UNITED STATES DEPARTMENT OF AGRICULTURE
Soil Conservation Service
H. H. Bennett, Chief

Investigations Pertaining to Run-off from Farm Land in Murray County, Minnesota

By

C. E. Ramser, Research Specialist in Hydrology

Originally Prepared in 1920
Slightly Revised February 1946

Contents

These investigations were made for the purpose of obtaining runoff and other hydraulic data required in the conomical design of open ditches and tile drainage systems. The results are especially applicable to southwestern Minnesota and to other sections of the country where the rainfall and watershed characteristics are similar. Rainfall and discharge measurements were made to determine the rates of runoff due to different rates and amounts of rainfall, and experiments were conducted to determine the coefficient of roughness, n, in Kutter's formula as applied to tile and open ditches. Mr. E. G. Minder, Civil Engineer, Slayton, Minnesota, rendered much valuable advice and assistance in planning and carrying out the work. The period of these investigations extended from March to September, 1920.

RUNOFF INVESTIGATIONS.

Figure 1 is a map showing the divides of the various watersheds and the locations of the different gaging stations where runoff measurements were made. Beaver Creek is the main drainage channel; it has its source in the northeastern part of Pipestone County and flows into the Des Moines River, being in reality the continuation of this river above the point where the outlet of Lake Shetek enters it. As shown in Figure 1, two tributaries unite to form the upper part of Beaver Creek. They are Judicial Ditch No. 14 (J14) and County Ditch No. 7 (C7). A third tributary, County Ditch No. 20 (C20), joins Beaver Creek about 2 miles west of Hadley. Gagings were made of these tributaries and of Beaver Creek near Hadley and Slayton. Gagings were also made of three tile-drained areas, namely, Judicial Ditch No. 15 (J15), County Ditch No. 11 (C11), and County Ditch No. 47 (C47), the locations of which are also shown in Figure 1.

GENERAL DESCRIPTION OF WATERSHEDS.

The extent and shape of the various watersheds are shown in Figure 1. There is very little timber on any of the watersheds. In general the soil may be described as a clay loam with a clay subsoil, and there are numerous gravel pockets of glacial origin scattered over the area. Bulletin No. 14, Minnesota Geological Survey, describes this section of the county as follows:

"The crest of the Coteau Des Prairies runs through the western part of the county, and is followed by a strong moraine. Parts of the moraine rise 1,900 feet above sea level and much of it above 1,800 feet, but there is a gap in it at Chandler which is only 1,550 feet. A few square miles on the east side of this moraine drain westward through this gap toward the Big Sioux River. The drainage of the eastern slope is chiefly to the Des Moines River. In the southwest part of the county the moraine just referred to becomes double and continues so southeastward into Iowa. The inner member makes a sharp loop northeastward to Hadley before taking this southeastward course. In this loop it has much gravelly drift, but elsewhere is

composed chiefly of clayey though rather stoney till. East of the moraine that forms the crest of the Coteau is a broad till plain covering more than half of the county and having a rich black clay loam soil."

The contour lines shown on the map were taken from the Minnesota Geological Survey map of the surface formations of Minnesota. The greatest difference in elevation is about 300 feet between the upper and lower end of the Beaver Creek watershed. Generally speaking the topography is rough and undulating, slopes of 30 to 40 percent being quite common. On the other hand there are many flat, swampy areas and numerous small lakes that comprise a considerable portion of the entire watershed area. A fair idea of the topography can be had from the accompanying photographs. Many of the flat areas are undrained and unproductive, except during dry years when yields of wild hay are sometimes harvested. Most of the other land is quite fertile and produces good yields of corn, oats, flax, rye, and hay.

FIELD MEASUREMENTS.

Rain gages were placed at Lake Wilson and Slayton. At Lake Wilson a Standard Weather Bureau gage was used, the gage being read at 6 p.m. At Lake Wilson the total amount of rainfall after each rain was measured. At Slayton a Friez self-recording tipping-bucket gage was installed. This gage indicated the rainfall in hundredths of inches and the time to approximately the nearest minute. (See fig. 2). U. S. Weather Bureau records of daily rainfall were obtained for Worthington, Minnesota, for 27 years. Daily rainfall for Worthington and Tracy from October 1919 to March 1920, and for Slayton and Lake Wilson for March to September. 1920, are shown in table 1.

As applied to these investigations the term runoff is used to denote that portion of the rainfall that finds its way to tile drains or open drainage channels. That part of the rainfall that does not appear as surface runoff on the watershed on which it falls may be lost through evaporation, may be used by vegetation, or may pass away into deep underlying strata.

Gagings of stream flow were made for computing the discharges of the streams at a number of stations, the locations of which are shown in figure 1. The velocity measurements of the large streams were made with a Gurley-Price cable-current meter, and of the small streams below the outlets of the tile drains with a Gurley-Price rod-current meter. Careful soundings were made at the time of gagings and during low water stages to determine the cross-sectional areas of the channels. The velocity measurements were made from bridges at intervals of 1 foot across the small channels and 5 feet across the large channels. Where the depth of the water permitted, measurements were made at top, middle, and bottom depths; where the water was very shallow, surface measurements were made. Where three measurements were made in the

TABLE I

Record of Daily Rainfall, October 1919 – September 1920

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
OCTOBER, 1919																															
Worthington					.38									.50	.05	.03	.03			.13					.10					.03	
Tracy				.37	.07				.18				.24	.09						.17				.35	.03		.16			.07	
NOVEMBER																															
Worthington			.05							1.45		.20															.20		.58		
Tracy									.97	1.80	.16															.05	.07	.25	.54		
DECEMBER																															
Worthington									.10																			.01			
Tracy												.02																			
JANUARY, 1920																															
Worthington							.20									.05		.20													.10
Tracy																		.18													
FEBRUARY																															
Worthington			.02	.10	.10								.20					.01			.30										
Tracy				.02									.03							.38								.04			
MARCH																															
Worthington				.80							.07	.08							.48					.40				.84			
Tracy			.80	.08							.02							.18	.17					.54				1.05			
Slayton																							.35					.33			
APRIL																															
Slayton									.14	.01									.33	.18	.05	.78			.87			.07	.59	.49	
Lake Wilson									.14	.12									.32	.24	.04	.47			1.13			.44	.85		
MAY																															
Slayton				.13							1.59	.26				.09			.27							.56					.02
Lake Wilson				.18							1.60	.35				.09			.25	.20						.72					
JUNE																															
Slayton	.28		.01	.12		.02				.16	.22			.15	.86	.29				.12	.06				.17		.07	.48		1.45	
Lake Wilson	.36		.02	.26					.07	.07	.67			.06	.92	.17				.01	.02			.06	.30		.77			1.25	
JULY																															
Slayton	.09			.66	.94	1.09	.83					.10						T	.05						.01						
Lake Wilson				.72	.62	.05	.75	.02				.02						.04	.04						.02						
AUGUST																															
Slayton			.77								.32			.16					.02									.40	.32		
Lake Wilson			.82								.59			.34	.06																
SEPTEMBER																															
Slayton		1.02	.57	.21	.01					.08													.71			No Record					
Lake Wilson			.56	.12						.14									.11							No Record					

same vertical, the mean velocity was computed by taking one-sixth of the sum of the velocity at the top, four times that at the middle, and the velocity at the bottom. The mean velocity for each interval was obtained by averaging the mean velocities found for the vertical lines on each side of the interval, and the discharge for each interval was obtained by multiplying this mean velocity by the cross-sectional area of the interval. The total discharge of the stream was the sum of the discharges of all the intervals. These discharge measurements were made for several stages of each stream, ranging from low to high stages.

The discharges, computed in cubic feet per second, were reduced to rates of runoff in inches per 24 hours from the entire watershed. Discharge curves for each of the streams were drawn using inches of runoff per 24 hours as abscissas and the corresponding water stages as ordinates, so that for any known stage of the stream the corresponding rate of runoff can be determined from the curves.

With the exception of the gaging stations J14 and Bear Creek at Slayton, where staff gages read daily were used, continuous records of the stages of the streams were obtained by the use of the Sanborn pressure gages. The height of the water in the channels was recorded on a circular chart by means of a pen whose movement up or down conformed to a corresponding movement of the water, the chart being revolved at a uniform rate by a clock (see figs. 3 and 4). The rates of runoff for the stages recorded for the streams were obtained from the runoff curves, and continuous hydrographs were plotted showing the rate of runoff at any time during the period of the investigation. These hydrographs for the larger streams are shown in figure 5, and for the tile drained areas in figure 6. Hydrographs for the drained areas plotted to a larger scale for the several important storm periods are shown in figures 7, 8, 9, 10, and 11. The record of rainfall is plotted beneath the hydrographs so that the relation between rainfall and runoff can be ascertained readily. In figures 5 and 6 the rainfall is plotted in inches per 24 hours; in the other figures in inches per hour.

RUNOFF IN OPEN CHANNELS.

County Ditch No. 7

Description of Channel and Watershed.

The watershed of County Ditch No. 7 is approximately fan-shaped and contains about 46.2 square miles. The length by channel from the upper edge of the watershed to the gaging station is about 14 miles. The slopes on the upper part of the watershed are quite steep. The average fall of the channel is about 6 feet per mile; small natural channels near the upper end have a fall of about 40 feet per mile. Drainage improvements consist of about 5 miles of dredged main channel and about 27 miles of tile for outlet drainage.

The area of the watershed of the tile-drainage system is about 5,000 acres and the area benefited by tile about 1,500 acres. Only the principal mains of the tile are shown on figure 1. There are no lakes of any importance on the watershed.

Runoff and Drainage Conditions.

Gagings of County Ditch No. 7 were made at the Highway Bridge on the State Road about 1 mile northeast of Lake Wilson. The channel at this point is old, tortuous, and unimproved. It is about 6 feet deep and has a bottom width of about 8 feet and a top width of 18 feet. A continuous record of the rates of runoff in inches per 24 hours for the period of investigations is shown in figure 5. The maximum stage in the channel occurred on May 12 at which time the maximum rate of runoff was 250 second feet or 0.2 inch per 24 hours from the entire watershed. This was due to a steady rain of 1.6 inches at Lake Wilson on May 11 which was the heaviest rain that occurred over the watershed during the period of investigations. A study of the rainfall records for 27 years at Worthington, Minnesota, show that such rains are likely to occur at least once a year during the period from April 15 to September 15.

Judicial Ditch No. 14.

Description of Channel and Watersheds.

The watershed of Judicial Ditch No. 14 adjoins that of County Ditch No. 7. It contains an area of about 25.5 square miles above the State road east from Lake Wilson. The length by channel from the upper part of the watershed to the gaging station is about 15 miles. The fall of the channel near the lower end is about 2½ feet per mile. Near the upper part of the watershed the slopes are quite steep. At the time the gagings were made, construction work, consisting of dredging open ditches and laying large tile, was being done. Approximately 20 miles of tiling had been completed at the time the gagings were made.

Runoff and Drainage Conditions.

Gagings of Judicial Ditch No. 14 were made at the highway bridge on the State Road about 2 miles east of Lake Wilson. They were made on the old unimproved crooked channel. The main dredged ditch had nott yet been dug to the State Road at the time the gagings were made. At the gaging station the old channel is about 5 feet deep and averages about 20 feet wide. A staff gage was placed at the bridge and daily readings were made of the stage of the water. Several readings were made daily during high water periods. The maximum rate of runoff occurred on May 12 (see fig. 5) for the same rain that produced the maximum stage in County Ditch No. 7. The rate

of runoff was 215 second feet or 0.314 inch per 24 hours from the entire watershed. This is over 50 percent larger than that obtained for County Ditch No. 7 due, no doubt, to the more extensive surface drainage improvements on the watershed. The large flat swampy area for some distance above the gaging station was overflowed and remained wet for a considerable period after the rain that produced the above rate of runoff.

County Ditch No. 20.

Description of Channel and Watershed.

The watershed of County Ditch No. 20 contains an area of about 40.6 square miles above the gaging station shown on the map. The length by channel from the furthest point on the watershed to the gaging station is about 11 miles. The fall of the channel just above the gaging station is about 5 feet per mile, and the fall of the channel in the lake beds is only about 1 foot per mile. Old lake beds and low lands comprise about one-fifth of the total area of the watershed, all of which are included in the drainage system of open ditches shown on the map. The lands outside the lake beds are not so steep as on the upper parts of the watersheds J14 and C7. About 6,000 acres of the watershed are served by 46 miles of tile drains of which about 2,700 acres are benefited.

Runoff and Drainage Conditions.

Gagings of the dredged channel of County Ditch No. 20 were made from a private highway bridge about 3 miles northwest of Hadley. The location of the gaging station is shown on the map. The channel section has a top width of 25 feet, a bottom width of 10 feet, and a depth of about 8 feet. A continuous record of the water stages was obtained by a self-recording gage. Hydrographs of the rates of runoff in inches per 24 hours are shown in figure 5, from which it is seen that a maximum rate of 0.21 inch per 24 hours or 230 second feet occurred on June 30. It is believed that this rate was as high as that which occurred on May 12 for which no record was obtained. The rainfall that produced this runoff was 1.25 inches at Lake Wilson and 1.45 inches at Slayton on June 30.

This ditch was planned to drain surface water from about 5,000 acres of shallow lakes. A large part of this land is only fit for the production of wild hay, except during dry years when corn and flax have been grown. Were it not for the fact that the water in the old lake beds and swampy areas reaches the dredged ditches very slowly and that the ditches in the lake beds have very little fall a much larger rate of runoff would have resulted.

Beaver Creek at Hadley.

Description of Channel and Watershed.

As indicated on the map (fig. 1) the watershed of Beaver Creek above the gaging station comprises the watersheds of C20, J14, and C7. The additional watershed, most of which is included in the drainage project J14, consists chiefly of low, wet, and poorly drained land, a small part of which has been tiled as indicated on the map. The total watershed contains an area of about 122 square miles. The distance from the furthest point on the watershed to the gaging station by channel is about 25 miles. The old channel at the gaging station has a fall of about 2 feet per mile and is very crooked. There are about 100 miles of tile drains on the watershed.

Runoff and Drainage Conditions.

Gagings of Beaver Creek were made at the highway bridge about 2 miles northwest of Hadley. The old channel at this point is abnormally wide, having an average width of about 40 feet and a depth of about 8 feet. In figure 5 is shown the runoff hydrograph for this stream. The maximum rate of runoff that occurred was 580 second feet or 0.18 inch per 24 hours on May 13. This was due to the rain that produced the maximum stages on C7 and J14. After this rain, much water accumulated over the low swampy land along the creek between the gaging station and the State road between Lake Wilson and Hadley.

Beaver Creek at Slayton.

Description of Channel and Watersheds.

In all, Beaver Creek above Slayton drains an area of about 157 square miles, about 35 square miles of which lies between the gaging stations near Hadley and Slayton as shown on the map. There are about 140 miles of tile on the watershed. There are no very large low flat areas along the creek between Hadley and Slayton. In some places the channel is bordered by rough high land on both sides. The distance from the furthest point on the watershed to the gaging station by channel is about 45 miles. The old channel at the gaging station has a fall of about 2 feet per mile.

Runoff and Drainage Conditions.

Gagings of Beaver Creek near Slayton were made from the concrete highway bridge about 1/2 mile north of Slayton on the State road. The old channel at this point has a bottom width of about 30 feet, top width of 60 feet, and a depth of about 8 feet. Stages of the stream were read daily during low water and several times daily during high water. It is seen from the hydrographs in figure 5 that the maximum rate of runoff during the period of investigations occurred

on July 1, which was 920 second-feet or 0.22 inch per 24 hours from the entire watershed. Before the stage in the channel had fallen much additional rains on July 4, 5, 6, and 7 caused a second rise and the water in the channel remained at a high stage for four or five days. This continued high stage greatly reduced the flow from a tributary underdrained area near Slayton and caused considerable damage to crops.

Summary for Open Channels.

Referring to the hydrographs of runoff for the open channels shown in figure 5, it will be seen that the maximum rates of runoff that occurred on Ditches C7, J14 and Beaver Creek at Hadley were due to the rain on May 11. Apparently this rain was not as heavy over the watershed of C20 as over the other watersheds. Also it can be seen that the rain on June 30 produced the maximum rate of runoff in C20 and Beaver Creek at Slayton. This rain apparently was heavier over the watershed of C20 and the lower part of the Beaver Creek watershed between Hadley and Slayton than on other parts of the watershed as indicated by the much greater rate of runoff obtained for C20 than that for the rain of May 11 and by the smaller amount of rainfall recorded for Lake Wilson than for Slayton. Hence it seems apparent that neither of the two rains that produced the highest rates of runoff was of the same intensity over the entire watershed of Beaver Creek. Also the rains that produced the high rates of runoff were not large, the rainfall for May 11 being 1.59 inches and 1.60 inches and on June 30, 1.45 inches and 1.25 inches at Slayton and Lake Wilson respectively. A study of the rainfall records at Worthington, Minnesota, shows the following number of one-day rains during 27 years.

Table 2.

Record of Heavy Rains at Worthington, Minnesota.

No. of Rains.	Amount in Inches Per 24 Hours.
41	$1\frac{1}{2}$ inches and over
21	2 " " "
10	$2\frac{1}{2}$ " " "
6	3 " " "

From table 2 it is seen that heavier rains are likely to occur quite frequently than occurred during the period of these investigations. A summary of the runoff and rainfall data is given in table 3. In making use of these data it should be remembered that the drainage situation on any of the watersheds is not satisfactory and that improvements are under way or contemplated for the thorough drainage of practically all of the watershed.

Table 3.--Runoff, Rainfall and Watershed Data for Open Drainage Channels in Murray County, Minnesota

Name of stream.	Watershed			Maximum rate of runoff.			Rainfall		
	Area	Length by channel.	Fall of channel	Date	Cu.ft. per sec.	Ins. per 24 hours.	Date	Slayton	Lake Wilson
	Sq.Mi.	Miles	Ft. Per Mile					In.	Inches
County Ditch No. 7	46.2	14	6	May 12	250	0.20	May 11	1.59	1.60
Judicial Ditch No. 14	25.5	15	2½	May 12	215	.31	May 11	1.59	1.60
County Ditch No. 20	40.6	11	5	June 30	230	.21	June 30	1.45	1.25
							May 11	1.59	1.60
Beaver Creek at Hadley	122.1	25	2	May 13	580	.18	May 12	.26	.35
							June 30	1.45	1.25
Beaver Creek at Slayton	157.4	45	2	July 1	920	.22	July 1	.09	--

The maximum rate of runoff from a watershed for a given rainfall intensity always occurs when water from every part of the watershed is reaching the channel at the lower end of the watershed. The rain producing this maximum rate must last as long as the time of concentration which is the time required for water to flow from the most remote point of the watershed to the lower end; and the greater the intensity of this rain, the greater will be the rate of runoff. It is well known that in a general way the intensity of rainfall varies inversely with the duration or in other words that very heavy rains do not last as long as rains of lesser intensity. From the above it is seen that the effect of reducing the time of concentration by increasing the velocity of the water in the channel is to produce higher rates of runoff.

The effect of open drainage ditches is to increase the velocity of the water, reduce the distance traveled by the water from the upper to the lower end of the watershed and thus reduce the time of concentration and produce a higher rate of runoff. Also less time is required to remove the surface water from the watershed. On the other hand the effect of tile drainage is generally to prolong the time required to remove that portion of the water that percolates into the soil since it flows to the tile through the soil very slowly. As a result the surface water runoff is reduced by the amount of water percolating to the tile, hence a reduction in the maximum rate of runoff results. An exception to the above is the case of a swamp or shallow lake with no surface outlet where tile drains remove the water from the area faster than before drainage and thus increase the rate of runoff.

Where a heavy rain continues after the soil has become thoroughly saturated so that as much of the water runs off as prior to drainage the maximum rate of runoff would remain practically unchanged. If for this same case open ditches had also been constructed, the effect would be to produce a higher maximum rate of surface runoff from the watershed. Where a combination of tile and open ditches is employed, a special study of each particular watershed is required to ascertain the probable effect upon the maximum rate of runoff. If the effect of reducing the time of concentration by the construction of open ditches is greater than that produced by the additional percolation of water into the tile drains, and maximum rate of runoff will be increased; if the reverse is true the maximum rate will be decreased.

RUNOFF FROM TILE-DRAINED AREAS.

County Ditch No. 47.

Description of System and Watershed.

The location of this tile-drainage system is shown in figure 1, and the location of the swamps and arrangement of tile lines on a large scale map is shown in figure 12. The watershed is practically fan-shaped and contains 0.528 square mile or 338 acres. The main tile discharges into an open ditch which in turn empties into Summit Lake. The main tile is 16 inches in diameter and has a fall at the lower end of 0.5 foot per 100 feet. The maximum fall of the branch tile is 6.5 feet per 100 feet. There are 2.94 miles of tile on the watershed, the smallest size of tile being 6 inches. An area of about 100 acres is benefited by the tile, 50 acres of which was virtually a swamp before drainage. The remainder of the watershed is rolling with very abrupt and steep slopes near the edges. During the summer of 1920 about 10 percent of the watershed was in corn and the rest was devoted to the growth of oats, flax, pasture, and meadow.

Runoff and Drainage Conditions.

Gagings of the flow from the tile were made from a foot bridge over the open ditch about 50 feet below the tile outlet. Views of the bridge and the outlet are shown in pl. 1, figs. 1 and 2. Fluctuations of the water surface were recorded by means of a pressure gage (Sanborn recorder) so that a continuous record of the water stages was obtained. In figures 7 to 11 are shown continuous hydrographs of the runoff in inches per 24 hours for storms during the period of these investigations. During the first part of the rains a heavy surface runoff generally occurred and these hydrographs include both surface and tile runoff.

In figures 13 and 16 the combined surface and tile runoff is shown as a full line and the tile runoff as a dotted line. The maximum rate of tile runoff of 0.32 inch per 24 hours was actually measured with the current meter. It is believed however that the rate of tile runoff was a little larger than this shortly before the gaging was made but it is impossible to determine just how much larger, since the stages recorded by pressure gage were for both tile and surface flow. There are no surface outlets on the watershed. Satisfactory drainage of the lands has been obtained and although the area that was a swamp before drainage remains wet a little too long after the heaviest rains it is believed that a few lateral tile lines laid in this area and a tile line to intercept the seepage from the adjoining high land would prevent this wet condition. Before drainage 50 acres of the swamp land was of practically no value for cropping purposes. The first year after drainage a crop of flax was cut from this swamp that yielded to the owner about $40 per acre and more than paid for the cost of drainage.

Table 4

Runoff, Rainfall, and Watershed Data for Tile Drainage Systems, in Murray County, Minnesota

Tile drainage system	Watershed area	Land benefited by drainage 1/	Total length of tile drains	Main outlet tile: Diameter	Main outlet tile: Fall at lower end	Max. fall of branch tile drains	Vegetation on watershed: Kind	Vegetation on watershed: Amt.	Maximum rate of tile runoff: Sec. ft.	Maximum rate of tile runoff: Ins. per 24 hours	Date
	Acres	Acres	Miles	Inches	Per ft 100 feet	Ft. per 100 ft		Per cent			
C47	338	99	2.94	16	0.50	6.5	Corn SmallGr	10	4.54	0.32	6/15/21
							Pasture and Meadow	90			
C11	1370	2/ 472	2/ 10.75	26	.20	3/ 5.1	Corn SmallGr	25	23.6	.41	6/15/21
							Pasture and Meadow	75			
C15	2430	735	11.88	30	.10	4.0	Corn SmallGr	25	37.8	.37	6/30/21
							Pasture and Meadow	75			

1/ Land benefited by drainage is land that always or periodically was too wet to cultivate prior to drainage. Additional land was made to yield somewhat larger crops after drainage.

2/ Includes Watershed C47.

3/ Below Summit Lake.

County Ditch No. 11.

Description of System and Watershed.

County Ditch No. 11 was constructed primarily to drain agricultural lands below Summit Lake and incidentally to furnish an outlet to the Lake. In the study of runoff, however, it is necessary to include in the watershed the entire area that has its outlet through the main tile drain of County Ditch No. 11. Such a watershed includes Summit Lake and County Ditch No. 47 and contains 1,370 acres of 2.14 square miles classified as follows: The lake contains an area of 75 acres; County Ditch No. 47, 338 acres; County Ditch No. 11 below the Lake, 807 acres; and the areas that drains directly into the Lake 150 acres.

As may be seen from figure 12 the main tile of C11 extends to the lake and drains the lake through a surface inlet. The top of the inlet was placed at the elevation at which it was desired to maintain the level of the lake and a concrete cut-off wall was built just below the inlet along the edge of the lake to prevent water from seeping through from the lake and keeping the land wet below. The main tile at the outlet is 26 inches in diameter and the tile at the lake is 15 inches in diameter. The maximum fall of the branch tile below the lake is 5.1 feet per 100 feet. There are 8.15 miles of tile on the watershed below the lake and 10.75 miles of tile on the entire watershed. About 375 acres of land benefited by the drainage improvements lie below the lake part of which was swamp before drainage. The rest of the watershed below the lake is rolling, and quite steep in places. The slopes are not as steep as on the watershed of C47. During 1920, about 25 per cent of the watershed was in corn and the rest in small grain, pasture, and meadow.

Runoff and Drainage Conditions.

Gagings were made at a foot bridge constructed about 50 feet below the outlet end of the tile shown in plate 11, figure 1. A continuous record of the water stages was obtained with a pressure gage similar to the one used for County Ditch No. 11. In figures 7 to 11 are shown continuous hydrographs of the runoff in inches per 24 hours for storm periods which include the combined tile and surface flow. In figures 13 and 14 are shown large scale hydrographs for the two storms that produced the maximum rates of runoff. The full lines represent the combined surface and tile flow and the dotted lines the tile flow. Gagings of the surface flow were made in an open ditch just before the water entered the main channel above the main gaging station.

All heavy rains produced two crests in the channel, the first was due to surface runoff and the second to both surface and tile runoff but principally to the latter as may be seen by examining the hydrographs in figures 13 and 14. The crest due to tile runoff generally occurred 2 or 3 hours after the crest due to surface runoff. The maximum rate of tile runoff occurred on June 15 and was 0.41 inch per 24 hours. This was due to a rain storm that passed between Slayton and Lake Wilson with its center about at Hadley. Records obtained at Hadley indicate that this rain amounted to about $2\frac{1}{2}$ inches and fell in about $2\frac{1}{2}$ hours. The rainfall for the same time at Slayton was about 0.69 inch and at Lake Wilson 1.00 inch. A more general rainfall of 1.42 inches at Slayton occurred on June 30. The maximum rate of tile runoff for this rain was 0.35 inch per 24 hours. During this rain the lake rose about 2 inches, and the rains on June 4 to 7 raised the level of the lake about 3 inches more.

Before drainage there was much swampy land of practically no value on the watershed and the land just below the lake was injured by seepage from the lake. This land has now been satisfactorily reclaimed for farming purposes.

Judicial Ditch No. 15.

Description of System and Watershed.

The location of this tile drainage system is shown in figure 1. The watershed has an area of 3.8 square miles or 2,430 acres. The main tile is 30 inches in diameter and discharges into a small open dug ditch that was formerly the natural drainage channel. In Plate II, Figure 2 is shown a view of the outlet end of the tile. The main tile has a fall of 0.1 foot per 100 feet and the maximum fall of the branches on the steepest part of the watershed is 4 feet per 100 feet. There are 11.88 miles of tile on the watershed, the smallest size being 6 inches. Seven hundred and thirty-five acres of land were assessed for benefits derived from the drainage system, about 275 acres of which was practically a swamp and of very little value before drainage. The land outside of the benefited area constitutes over 75 per cent of the watershed. This land is rolling and has quite abrupt and steep slopes in places throughout the watershed and particularly around the edges. As may be seen from the map, figure 15, there are several large branch-tile systems which tend to concentrate the water in the main and produce a large rate of runoff. There are no specially constructed surface inlets on this system but a number of manholes were built along the lower 2,000 feet of the main tile for experimental purposes that acted as inlets when the low flat land just above the road was overflowed.

Runoff and Drainage Conditions.

Gagings of Judicial Ditch No. 15 were made in the open ditch about 100 feet below the tile outlet. A pressure gage was used to record the stages in the channel continuously. figure 6 is a hydrograph of runoff for the entire period of investigation, figures 7 to 11, are hydrographs for the principal storm periods, and figures 13 and 14 for the two storm periods for which the greatest rates of runoff occurred. In figures 13 and 14 the combined tile and surface runoff is shown by the full line and the tile runoff by the dotted line. The surface water flowed into the ditch over the top of the headwall of the tile outlet (see plate III), fig. 1). Gagings of the surface flow were made above the tile outlet. As may be seen from figures 13 and 14, two distinct crests occurred for the heavy rains that fell on June 15 and 30. The crest due to the tile water flow occurred 5 to 6 hours after the crest due to the surface water. Most of the surface water drained from the surrounding rolling and hilly land near the lower end of the watershed. The maximum rate of the tile runoff occurred on June 30 and was 0.37 inch per 24 hours due to a rain of 1.42 inches which fell in about 3 hours.

Before drainage there were numerous swamp areas over the watershed (about 275 acres in all) that had no surface outlets. They were unfit for cropping purposes and only during dry years was an occasional cutting of wild hay obtained. The rest of the land benefited by drainage (about 460 acres) lies along the watercourses as shown on the map. This land is well drained. Considerable lateral drainage will be required in the swamps before satisfactory drainage will be obtained. During June and July, water due to heavy rains stood over the large swamps located mostly in the northwest quarter of section 6, and did considerable damage to the corn and hay crops. About $2\frac{1}{2}$ inches of rain fell at Hadley in two hours on June 15 and it is believed that the rainfall was heavier over the watershed of Judicial Ditch No. 15. The path of the heaviest precipitation for this storm was between Slayton and Lake Wilson, no heavy rainfall occurring at either of these places.

Judicial Ditch No. 15 affords the best opportunity for a study of the flow of water from a tile-drained area, since the best and most reliable records were obtained for this ditch. A study of the hydrographs for Judicial Ditch No. 15 reveals a number of facts relative to the flow of water from tile-drained areas. The hydrographs in figures 13 and 14 show two distinct crests. The first crest which occurred shortly after the greatest intensity of rainfall is due to surface runoff from the lower part of the watershed, and the second crest which occurred 5 or 6 hours later was due to the tile-water runoff. It is not likely that either of these crests, and especially the first, would have been observed were it not for the self-recording gage which furnished the continuous record of the stage of the water. For the

reason that the maximum rate of surface runoff occurs during a rain or very shortly after, it is rarely probable that a person would be on hand to observe the high stages due to surface runoff, and no doubt accounts for a commonly prevailing opinion that the tile carries all the runoff from a watershed.

Tile Water Flow Resulting from Winter Snows and Spring Rains.

Attention is called to the hydrographs shown in figure 7 and particularly to the one for Judicial Ditch No. 15. Until the latter part of March a thin crust of frost remained in the ground. A rain of 0.33 inch fell on March 28 and produced a maximum rate of 0.11 inch per 24 hours in the open ditch, Judicial Ditch No. 15. This rate was due to surface runoff from the area near the gaging station and the crest occurred before the rain had ended. Practically no water from this rain reached the tile until late on the 29th when it began to show up in the ground-water flow. However, during the night of the 29th the flow decreased but before noon on the 30th a very rapid rise occurred and a maximum rate of runoff of 0.23 inch per 24 hours resulted. The average minimum temperatures during these three days for Pipestone, Tracy, and Worthington were 30, 20, and 28 degrees F. and the average maximum temperatures were 65, 42, and 59 degrees F. for March 28, 29 and 30 respectively. It is believed that the hydrographs can be explained as follows: On March 28, the frozen crust in the ground was rapidly melting away but had not yet melted sufficiently to permit the rain to penetrate it. This melting continued and during the morning of March 29 the crust permitted some of the water to trickle through as indicated by the rise in the ground-water flow on March 29. During the night of March 29 the temperature dropped, a cessation of the water trickling through the crust of frost occurred, but with the rise in temperature the next day the crust gave completely away and the ground water flowed unimpeded to the tile and produced the high rate of runoff that occurred on March 30. The rain of 0.33 inch on March 28 played a very small part in producing this high rate of runoff which was due principally to water stored in the soil above the frozen crust of earth contributed by melting snow and light rains that occurred during the winter and spring. (See table 1.) This is believed to be a correct explanation for what appeared at the time to be a peculiar action of the flow since there were no rains on either the 29th or 30th and there was no snow on the ground that could have melted and produced this unusual flow. The above explanation incidentally accounts for the fact that tile-drained roads in this vicinity remain wet in the spring and are often practically impassable until the last crust of frost breaks up and permits the stored up soil water to drain away.

ROUGHNESS COEFFICIENT IN KUTTER'S FORMULA.

Data were secured for determining the value of $\underline{n}$ in Kutter's formula, on County Ditch No. 20, Judicial Ditch No. 15 and in the 30-inch concrete tile. The term $\underline{n}$ in Kutter's formula is a measure of all the conditions in the channel that tend to retard the flow of water. A full discussion of this subject will be found in Department Bulletin 832, "The Flow of Water in Dredged Drainage Ditches," and Department Bulletin 854, "The Flow of Water in Drain Tile".

County Ditch No. 20.

A straight course of channel 600 feet in length was selected just above the gaging station. An average cross section showing the general shape and size of channel is shown in figure 16. In figure 17 is shown the per cent variation from the average cross-sectional areas for all cross sections along the slope course for a low, intermediate, and high stage. It will be noted that the variations in cross sections are much less for the highest stage than for the two lower stages. The values of $\underline{n}$ =0.050 and 0.047 were obtained for measurements Nos. 1 and 4, table 5, for a low stage and fairly high stage. These measurements were made during May before the grass in the channel had attained much growth. The other values of $\underline{n}$ are much higher and were obtained later after a heavy growth of wild grass had appeared in the channel. For these measurements the grass in the channel greatly reduced the effective cross-sectional area and as may be seen from the table higher values of $\underline{n}$ were obtained. The irregularities in the perimeter and the variations in cross section are also partly responsible for the high values of $\underline{n}$. Were it not for the grass, however, it is believed that the value of $\underline{n}$ for this channel at high stages would be about 0.035 or .040 instead of 0.065. These experiments show that in order to secure the maximum hydraulic efficiency of a ditch it is important to keep it free from grass or any other growth.

Judicial Ditch No. 15.

A course of channel 220 feet in length with an easy curve was selected just below the outlet end of a 30-inch tile. Gagings were made near the upper end of the course from a footbridge shown in plate IV, figure 1. An average cross section showing the general shape and size of the channel is shown in figure 18. In figure 17 is shown the per cent variation from the average cross-sectional area for all cross sections along the slope course for a low, intermediate, and high stage. The perimeter of the channel was quite irregular and there were many rocks on the bottom and side of the channel that tended to retard the flow and cause the formation of eddies during low stages. As a general rule this channel represents fairly well the condition of

small open channels below tile outlets in this section of the State where they have not been allowed to become choked up with grass and weeds. The grass on the side slopes of this channel is short due to the fact that it is pastured. It is believed that in planning channels of this size below tile outlets in this section of the State that a value of n of 0.045 should be used. The results of the experiment are given in table 5.

Table 5.-- Hydraulic Elements and Values of n in Kutter's Formula for Open Channels.

County Ditch No. 20.

No.	Date of observation	Average maximum depth	Average surface width	Discharge	Average cross section	Mean velocity	Mean hydraulic radius	Slope of water surface	Coef. C in formula $V=C\sqrt{RS}$	Coef. of roughness N
		Feet	Feet	Sec.Ft.	Sq. Ft.	Ft.Per Sec.	Feet			
1	May 13	3.9	19.1	118.7	48.3	2.46	2.21	.00093	54.3	0.0305
2	May 26	1.8	11.1	16.7	14.4	1.16	1.16	.00077	38.8	.0354
3	June16	3.8	18.5	85.5	45.5	1.88	2.14	.00095	41.7	.0389
4	June17	3.3	16.7	64.4	36.6	1.76	1.92	.00087	43.1	.0367
5	July 1	4.8	22.6	137.6	64.5	2.13	2.51	.00108	40.9	.0413
6	July 6	4.6	21.8	117.7	61.0	1.93	2.46	.00093	40.4	.0416
7	July 8	4.5	21.3	121.3	58.3	2.08	2.41	.00100	42.4	.0394

Judicial Ditch No. 15

1	May 13	1.4	7.0	9.74	6.6	1.47	0.83	.00345	27.5	0.045
2	June19	1.6	7.9	13.44	8.1	1.66	.92	.00377	28.2	.045
3	June18	1.8	8.4	17.11	9.2	1.86	.98	.00386	30.3	.043
4	May 12	1.9	8.8	20.16	10.2	1.97	1.02	.00395	31.0	.043
5	May 11	2.0	9.1	23.00	10.9	2.11	1.05	.00409	32.2	.042
6	June17	2.0	9.2	24.57	11.3	2.17	1.07	.00409	32.8	.041
7	June16	2.2	10.0	31.93	13.7	2.33	1.19	.00491	30.5	.045

Experiments on the Flow of Water in a 30-Inch Concrete Tile.

Experiments on the flow of water in concrete tile were conducted on the 30-inch main outlet tile of Judicial Ditch No. 15. For slope and current-meter measurements manholes made of 30-inch concrete tile were constructed 1000 feet apart, the lower manhole being 234.5 feet above the outlet of the tile. Levels were run between these manholes and the elevations of points established from which the elevation of the water surface could be determined by vertical measurements. From these elevations the slope of the water surface was computed and current-meter measurements were made both in the lower manhole and in the ditch about 50 feet below the outlet of the tile. The manholes were built so as to cause practically no interference with the uniform flow of water in the tile. Eight-inch holes were cut at a joint in the top of the tile and 30-inch tile was set vertically over them with the holes about in the center of the manhole. The manhole tile were cemented around the bottom and at the joints to prevent leakage when the tile was flowing under pressure. In order to determine the hydraulic gradient for some distance above the upper manhole when the tile was flowing under pressure three 12-inch tile observation wells were built at distances indicated on the profile in figure 19.

The section of tile where the experiments were conducted was straight and 1000 feet in length. Mr. E. G. Minder, Engineer in charge of construction, stated that the tile were well laid. Inspection at the two manholes indicated that the elevation of the abutting tile at the joints varied from one-half to three-fourths of an inch. The tile was clean and free from any sort of growth.

In table 6 are given the results of the experiments. Measurements of the discharge and slope of the hydraulic gradient were made for depths of flow of 0.67 foot to full with ratios of depth of flow to diameter of tile ranging from 0.27 to 1.00. The depth of flow was taken as the average of the depth at the upper and lower manholes. The area of flow used in the computations were taken as the average of the areas at the upper and lower manholes which explains the fact that the average depths of flow given in the tables do not correspond to the average area of flow. The hydraulic radius was taken as the average of the hydraulic radius at the two manholes. While it is fully realized that the above methods of averaging and of taking the fall of water surface as being uniform from the upper to the lower manhole are not entirely correct, particularly when the flow at the upper manhole is under pressure, still it is believed that the results obtained are sufficiently accurate and reliable for all practical purposes.

Table 6.—Results of Experiments on the Flow of Water in a 30-Inch Concrete Tile.

No.	Depth of flow (d) feet	d/D	Average area of flow (a) Feet	a/A	Average hydraulic radius (R) Feet	Discharge (Q) Cu. ft. per sec.	Mean velocity (V) Feet Per sec. ft.	Slope (s)	Chezy coefficient (C)	Kutter coefficient (N)
1	2.50	1.00	4.91	1.00	0.625	29.96	6.10	.00551	103.9	0.0133
2	2.48	.99	4.90	.99	.638	23.00	4.69	.00257	115.8	.0122
3	2.48	.99	4.90	.99	.638	21.21	4.33	.00239	110.9	.0126
4	2.45	.98	4.87	.99	.666	20.16	4.14	.00210	110.7	.0126
5	2.26	.90	4.58	.93	.702	17.11	3.73	.001345	121.3	.01185
6	1.92	.77	4.03	.82	.753	13.44	3.33	.001126	115.0	.0126
7	1.59	.64	3.28	.67	.713	9.74	2.97	.001017	110.3	.0127
8	1.31	.52	2.60	.53	.640	6.56	2.52	.000966	101.3	.0135
9	1.21	.48	2.35	.48	.610	4.95	2.11	.000966	86.9	.0154
10	0.74	.29	1.22	.25	.420	1.63	1.34	.000976	66.1	.0178
11	0.67	.27	1.06	.22	.388	1.31	1.24	.000966	60.1	.0186

D = Diameter of Tile.

A = Cross-sectional Area of Tile.

For Measurement No. 1 the tile was flowing under pressure at both manholes with a hydraulic gradient 5-1/2 times as large as the grade of the tile. For Measurement No. 2, 3, and 4 the tile was flowing under pressure at the upper manhole with a hydraulic gradient from 2 to 2-1/2 times as large as the grade of the tile. For Measurement No. 5 the tile flowed nearer full for many measurements made when there was no pressure at either the upper or lower manholes. For the remaining measurements the tile was flowing partly full and under no pressure. Values of n in Kutter's formula were computed for the several measurements. The smallest value of n obtained was 0.01185 for Measurement No. 5 for the tile flowing nearly full and under no pressure. For the tile flowing under pressure the values of n are higher and the highest was obtained for the tile flowing under pressure at both manholes. For the tile flowing partly full the value of n increases quite uniformly as the depth of flow decreases and is 0.0186 for a depth of flow of 0.67 foot or a ratio of 0.27 of depth of flow to diameter of tile.

From these data it appears that Measurement No. 5 for which a value of n of practically 0.012 was obtained represents most nearly the condition of flow met with generally in practice where the tile flows nearly full and not under pressure. The values in the table indicate that a somewhat higher value of n should be used in computing the flow of water in tile under pressure.

GENERAL DISCUSSION AND RECOMMENDATIONS.

In table 2 is given a list of rains greater than $1\frac{1}{2}$ inches that have occurred during 27 years at Worthington, Minnesota. During this period 10 rains of over $2\frac{1}{2}$ inches occurred. Unfortunately the rain that occurred on June 15 during these investigations was not general, a much greater amount of rain falling at Hadley than at either Slayton or Lake Wilson. About $2\frac{1}{2}$ inches of water was caught in a bucket at Hadley and it is believed that the rainfall over the larger part of the tile-drained watershed was somewhat larger judging from reports of a number of farmers. The rains that occurred on June 30 and the following several days, although not large, produced high rates of runoff since they were preceded by the heavy rain of June 15.

In view of the above, the rates of runoff measured are perhaps about what could be expected once in three years judging from the rainfall records for 27 years at Worthington, Minnesota. It is believed that they represent fairly well what should be the basis for design in order to secure the proper benefits from drainage.

In table 4 is given a brief summary of the runoff, rainfall and watershed data collected for the tile drainage systems.

The topography of the three tile-drained areas for which runoff data were obtained is distinctly different from the usual tile-drained watersheds found throughout Iowa and Illinois, where it is quite common to drain an entire watershed, all of the land in the watershed being benefited by tile drainage. In this section the land benefited by tile drainage systems usually constitutes from one-fifth to one-half of the area of the entire watershed, and lies in narrow strips along the watercourses, in small flat areas in the upper parts of the watershed, in low swampy areas with practically no surface outlets, or in former lake beds.

On a watershed that is comparatively flat or slightly rolling the rains have a better opportunity to soak into the ground and hence more water would reach the tile through the ground than where the slopes of the land are steep and the rain water has an opportunity to run off over the surface to a point below the outlet of the tile. The greater the intensity of the rainfall the greater the percentage of the rain that runs off. In this section, as has been stated, a large proportion of the watershed is steep or rolling but the water which runs off the slopes during heavy rains usually accumulates over the low lands that were formerly swamps or lake beds and is unable to escape since these low-lying areas, as a rule, have no surface outlets. The result is that the water must stand over this land as it did before drainage, until the tile is able to carry it away. This is practically equivalent to increasing the rainfall over the low-lying lands.

Some farmers favor the construction of surface inlets in these low areas that have no outlet for surface flow. The principal arguments against this practice, however, is that the tile below the surface inlet is maintained to its full capacity of flow until nearly all of the surface water from the swamp or depression is drained away. As a result the land below the inlet is not permitted to drain or only very slowly until the land above has gotten rid of its surface water and a large part of the ground water. It is apparent that this practice would be unfair where the lands below are assessed for the same benefits as the lands above the inlet. However, the installation of a surface inlet would not be unfair to the land below where the surface water from the land above would drain away through the inlet before the ground water reached the tile in large quantities. The runoff hydrographs for Judicial Ditch No. 15 show that there is a period of from 5 to 6 hours for this tile system between the crest of the surface flow and the ground water flow. During this time the tile is not flowing to full capacity and could be utilized for removing surface water from depressions. There are so many factors as regards characteristics of watersheds and nature of rainfall which modify runoff that in using surface inlets it is generally advisable to provide sufficient capacity for both surface and ground-water flow.

In selecting a runoff coefficient for a surface drainage system considerable weight is usually given to the influence of the size and shape of a watershed upon runoff. A larger rate of runoff per square mile of watershed is used for a small than for a large watershed and for a round, compact, fan-shaped watershed where there are several branches that delivers the water quickly to a point near the outlet than for a long narrow watershed with one main channel and numerous short branches. It is not believed that differences in size and shape of watersheds for areas no larger than that of J15 have a very decided effect upon the rate of runoff from tile drains with no surface inlets. The rate of ground-water flow to the tile is very slow as compared with the velocity of water in the tile and the crest of the ground-water flow continues at practically the same stage long enough, in most cases, to allow water from the entire drainage area to reach the outlet at the same time.

It will be noted in the hydrographs for the tile-drained areas that rates of surface runoff were obtained of from 2 to 4 times the maximum rates of tile runoff. This surface flow came principally from the lower parts of the watershed and is of no particular value as indicating the rates of surface runoff unless a careful analysis of all the factors influencing surface flow is made, such as water ponded in depressions, lakes or swamps; roads across the watercourses with inadequate culverts; natural watercourses very poorly defined and choked with growth; etc. In fact, the surface flow was impeded in many ways except near the lower end of the watershed. No provision was made for surface runoff and over the larger part of the watersheds nearly all the surface water ultimately reached the tile and passed off as ground-water flow.

The rains that do the most damage to crops in this section occur in the late spring or early summer. It is true that heavy rates of runoff occur in the early spring due to the accumulation of snow water during the winter, which completely saturates the soil and renders it unfit for tillage. This stored water drains away as soon as the frost breaks up and usually not until this time is the farmer ready to commence spring operations. The occasional rains that come in the late summer and early fall do practically no damage to crops. The soil at this season is usually dry and deficient in moisture and is able to absorb and hold a large portion of the rainfall, and vegetation utilizes a large quantity of water at this season of the year. This is illustrated by the fact that the rains that occurred during August produced very little runoff. (See fig. 5.)

There are so many conditions and characteristics of watersheds affecting runoff that to recommend a flat rate of runoff for the design of tile-drainage systems even for a particular locality is not advisable. In addition to the variable conditions already mentioned, these experiments reveal a few special points bearing on the subject. The rate of runoff for Judicial Ditch No. 15 was much larger than it would have been if the surface water had not been stored up over the

swamp areas but could have flowed over the surface unimpeded to the open ditch below the tile outlet. The computed capacity of the 30-inch main outlet tile with its grade of 1 foot in 1000 feet and a value of n equal to 0.012 is 14.4 cubic feet per second. However, the greatest discharge of this tile was about 37.8 cubic feet per second. This discharge was due to a pressure head of about 6 feet in addition to the 1 foot fall of the tile in 1000 feet. In planning the size of the tile, a hydraulic gradient was used that took into account this pressure head which was caused by a change in the grade line of the tile from a steep to a flat slope about 2000 feet above the outlet. (See Experiments on the Flow of Water in a 30-inch Concrete Tile, page 20, table 6.)

The above discussion serves to show the importance of making a careful analysis of all factors that combine to determine the rate of runoff for any particular project. No flat rate of runoff is recommended for use in this locality. It is believed that the proper rate of runoff to use lies between one-fourth to one-half inch where no provision is made for surface inlets. The rate of one-fourth inch should be used for the flat or slightly rolling areas with practically no swamp land or low land without surface outlets and the higher rate of one-half inch for watersheds where a large proportion of the area is steep and contains numerous large swamps or low lands with no surface outlets. Where surface inlets are used higher rates of runoff would be required depending upon the local conditions and upon the number, size and location of the inlets. Only after a careful study of conditions by a competent and experienced drainage engineer should a decision as to the proper rate of runoff be made, since the economical and efficient planning of a large tile drainage system depends primarily upon the proper selection of the runoff coefficient.

Plate I, Figure 1.--Gaging station on open ditch below tile outlet of County Ditch No. 47 showing footbridge staff gage and pressure gage box.

Plate I, Figure 2.--Sixteen inch tile outlet,
County Ditch No. 47

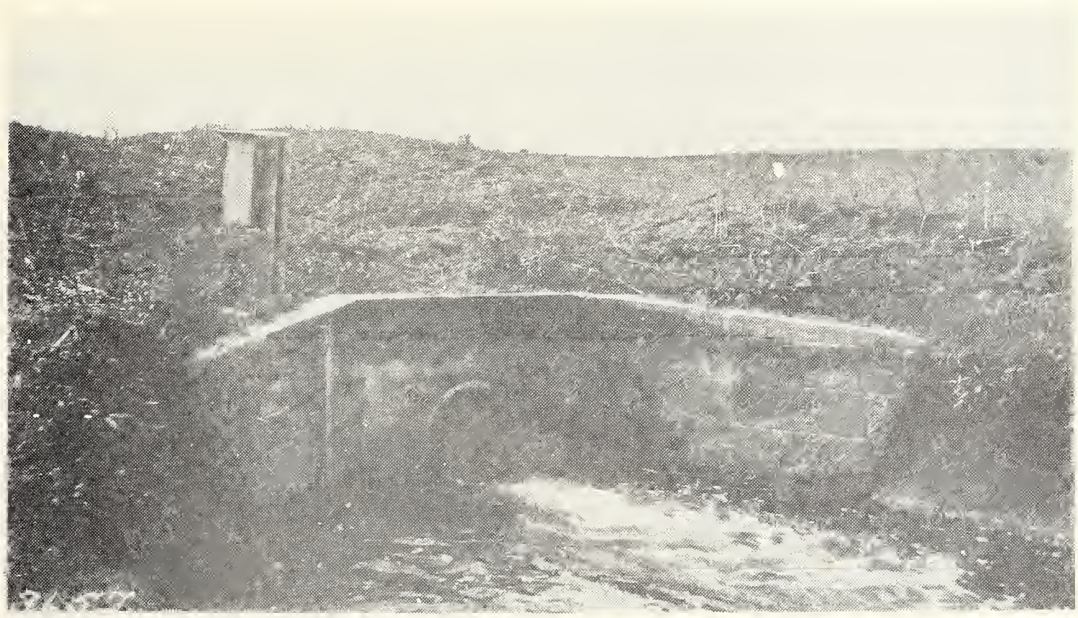

Plate II, Figure 1.--Twenty-six inch tile outlet, County Ditch No. 11. Note pressure gage box at left

Plate II, Figure 2.--Thirty inch tile outlet, Judicial Ditch No. 15

Plate III. Figure 1.--Surface water flowing over headwall at tile outlet, Judicial Ditch No. 15

Plate IV, Figure 1.--Gaging station and upper end of slope course of Judicial Ditch No. 15

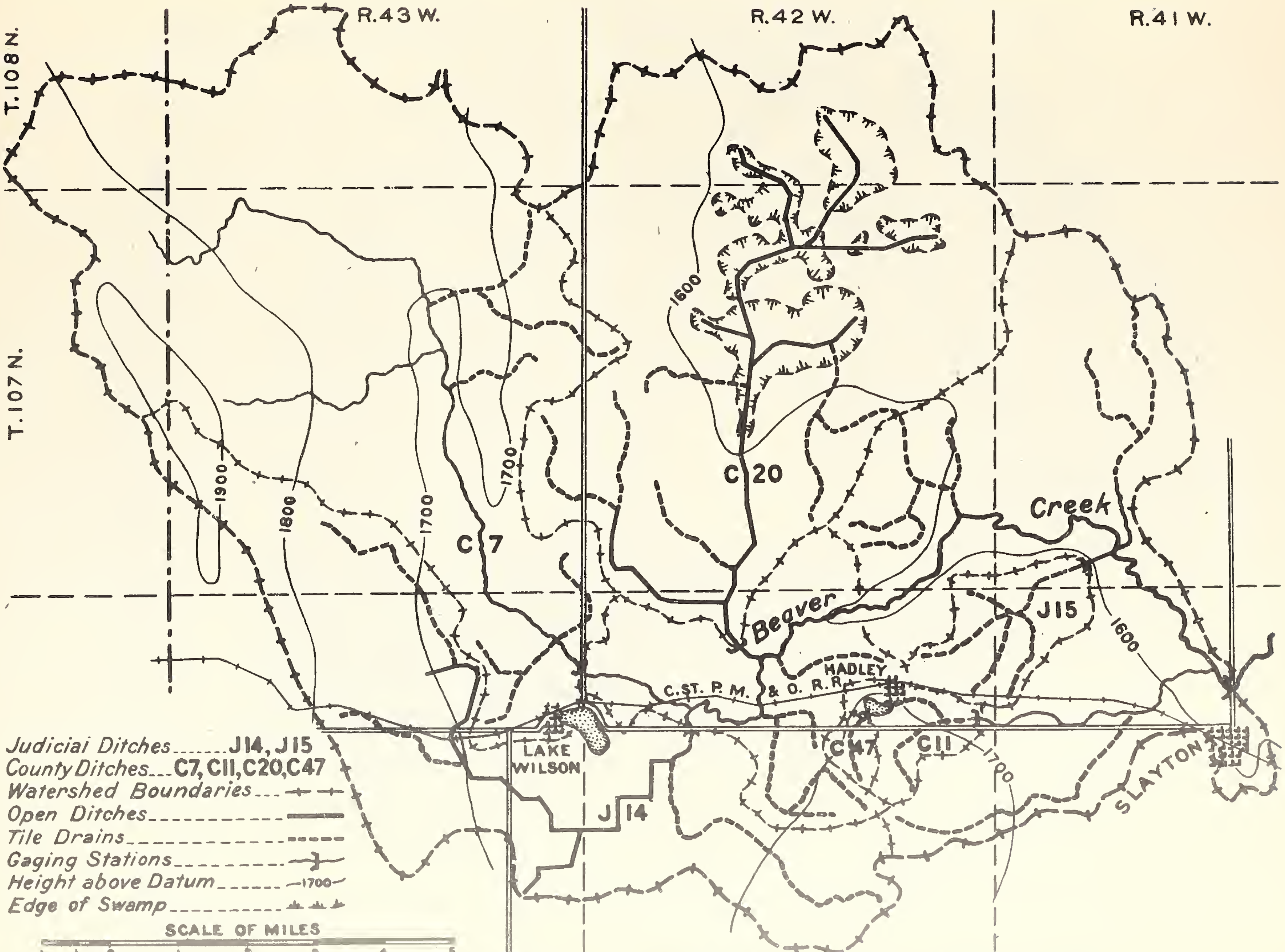

Fig. I. Watershed Map. Beaver Creek, Murray Co., Minnesota

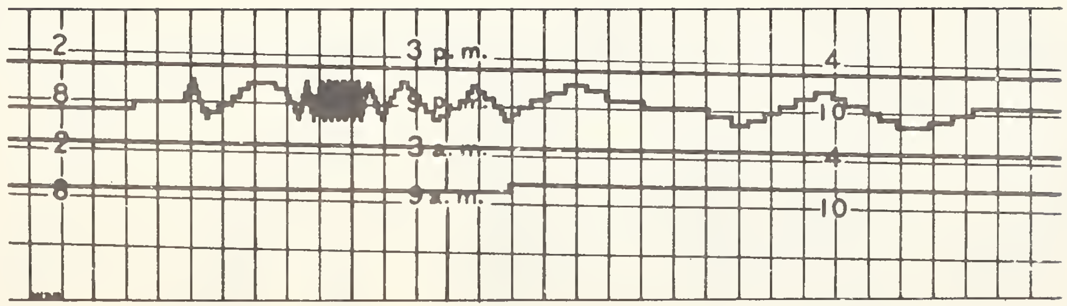

Fig. 2. Record of Rainfall at Slayton, June 30 and July 1, 1920
Obtained with a Selfrecording Rain Gage. *Each Step Represents .01 inch of Rainfall*

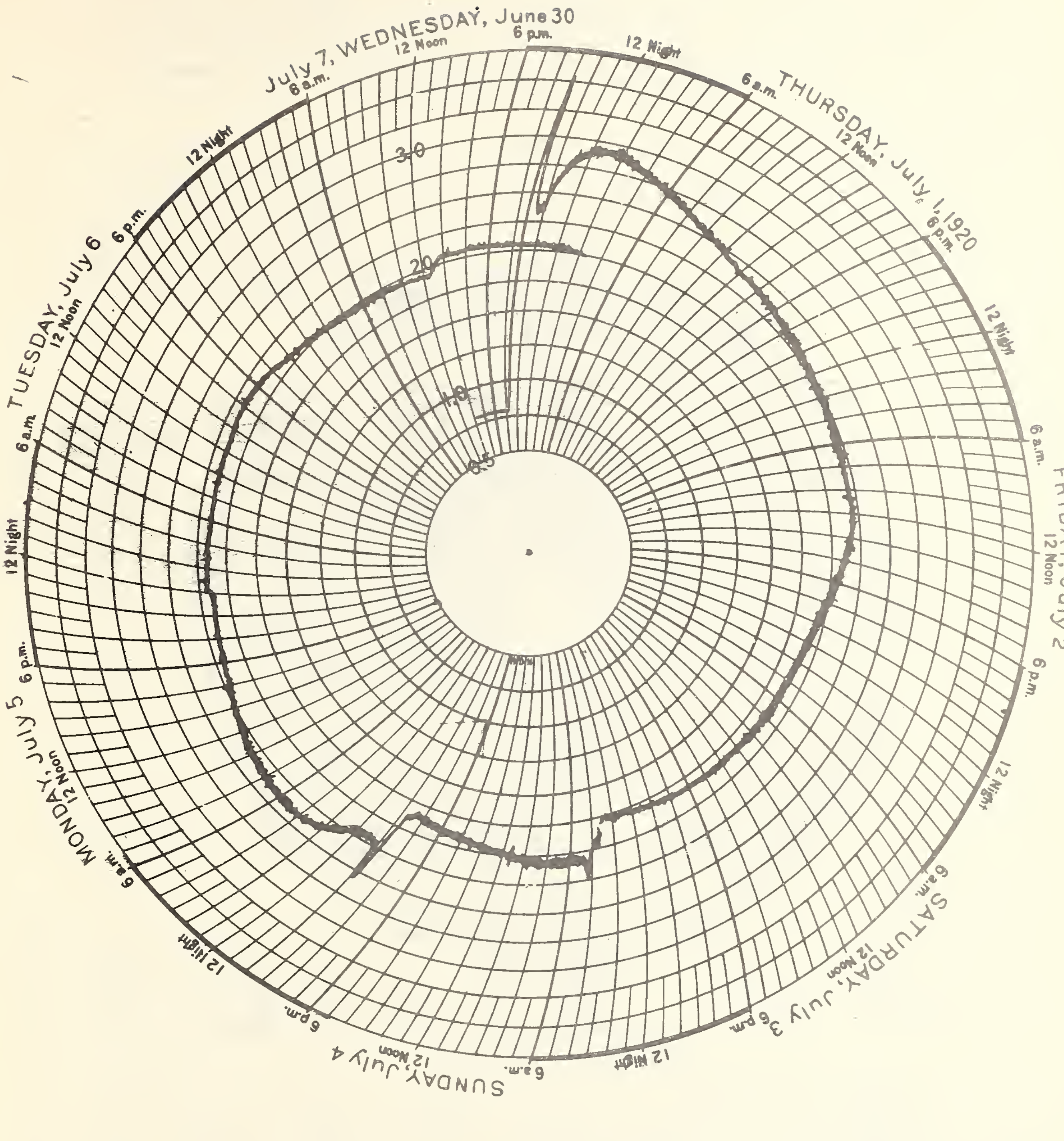

Fig. 3. Weekly Record Chart of Water Stages in Judicial Ditch No. 15 Obtained with Pressure Recorder

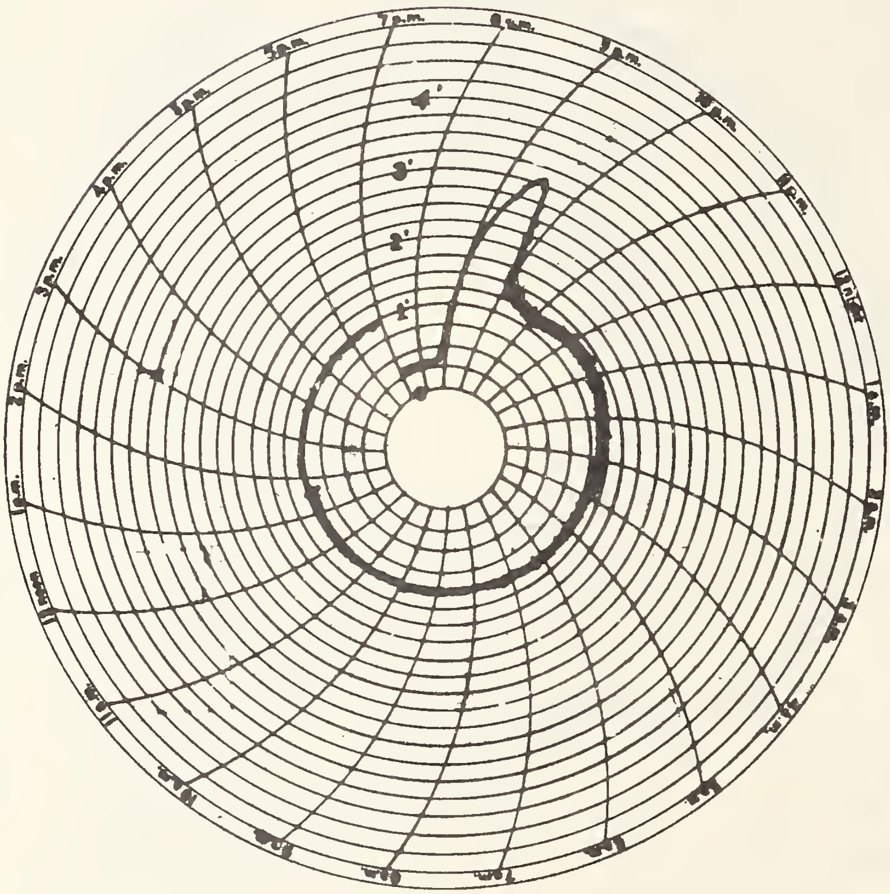

Fig. 4. Daily Record Chart of Water Stages Obtained with Pressure Recorder

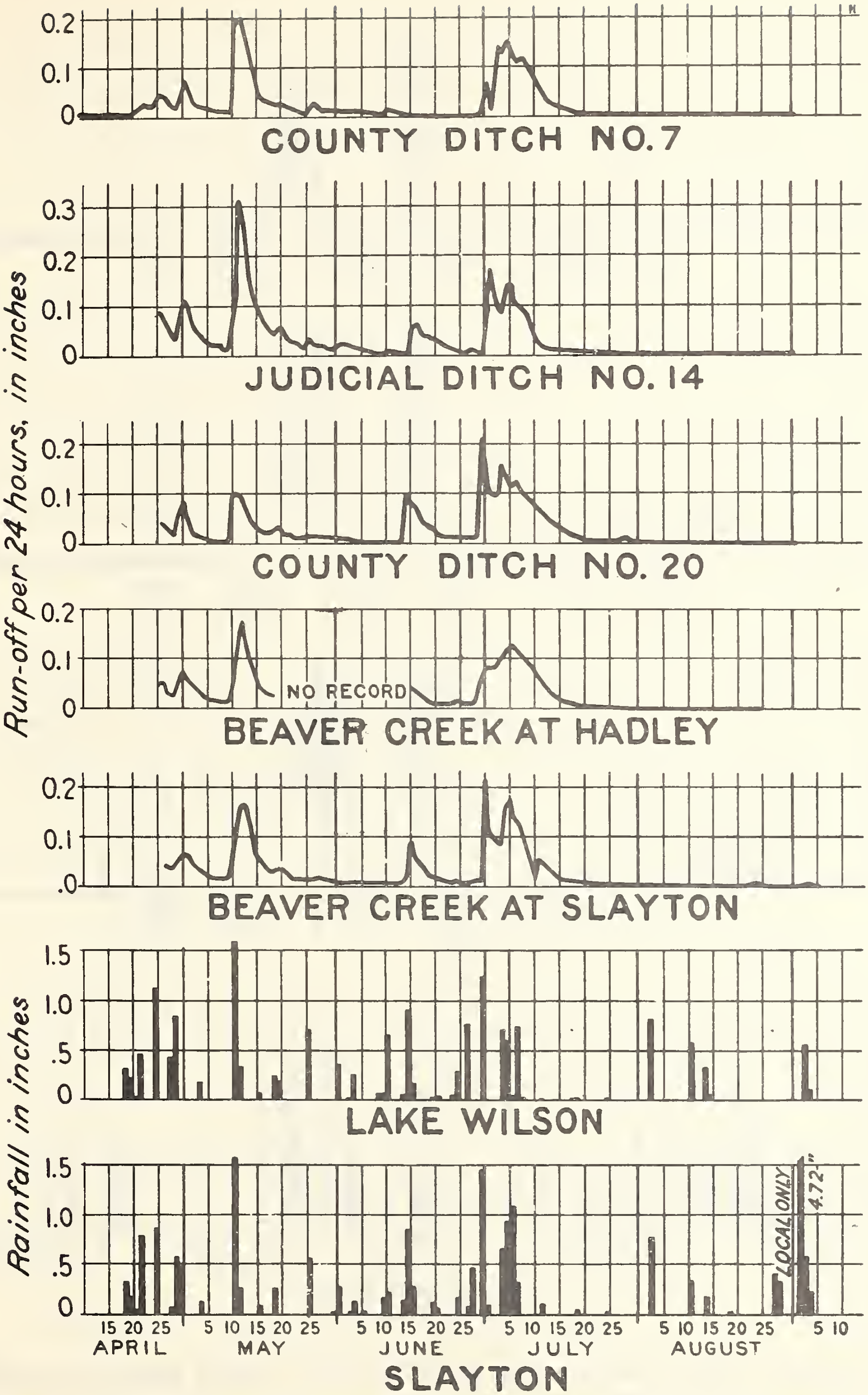

Fig. 5. Run-off Hydrographs and Rainfall Data 1920, Murray Co., Minnesota
Open Drainage Channels

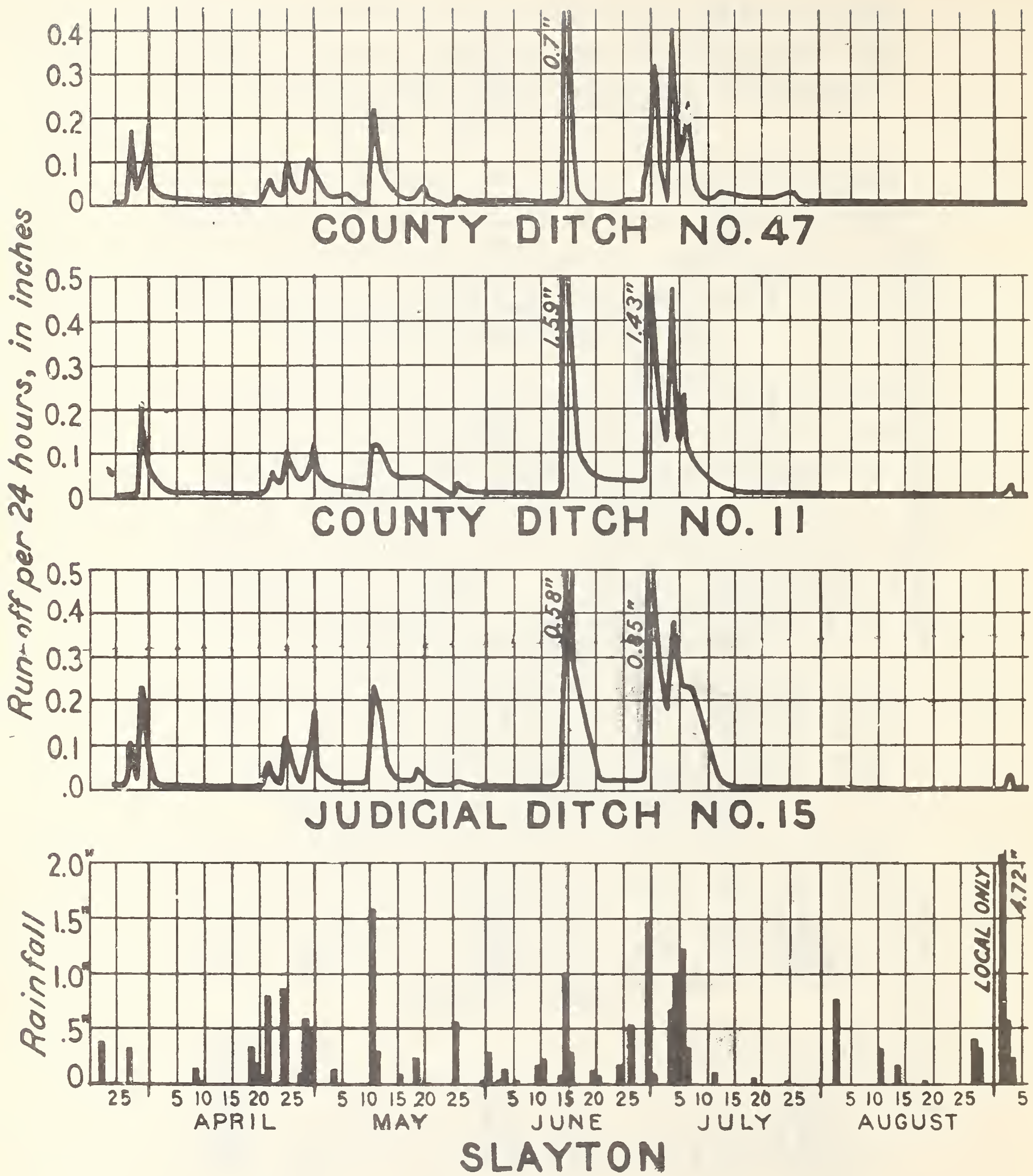

Fig. 6. Run-off Hydrographs and Rainfall Data, 1920, Murray Co., Minn. Tile Drainage Systems

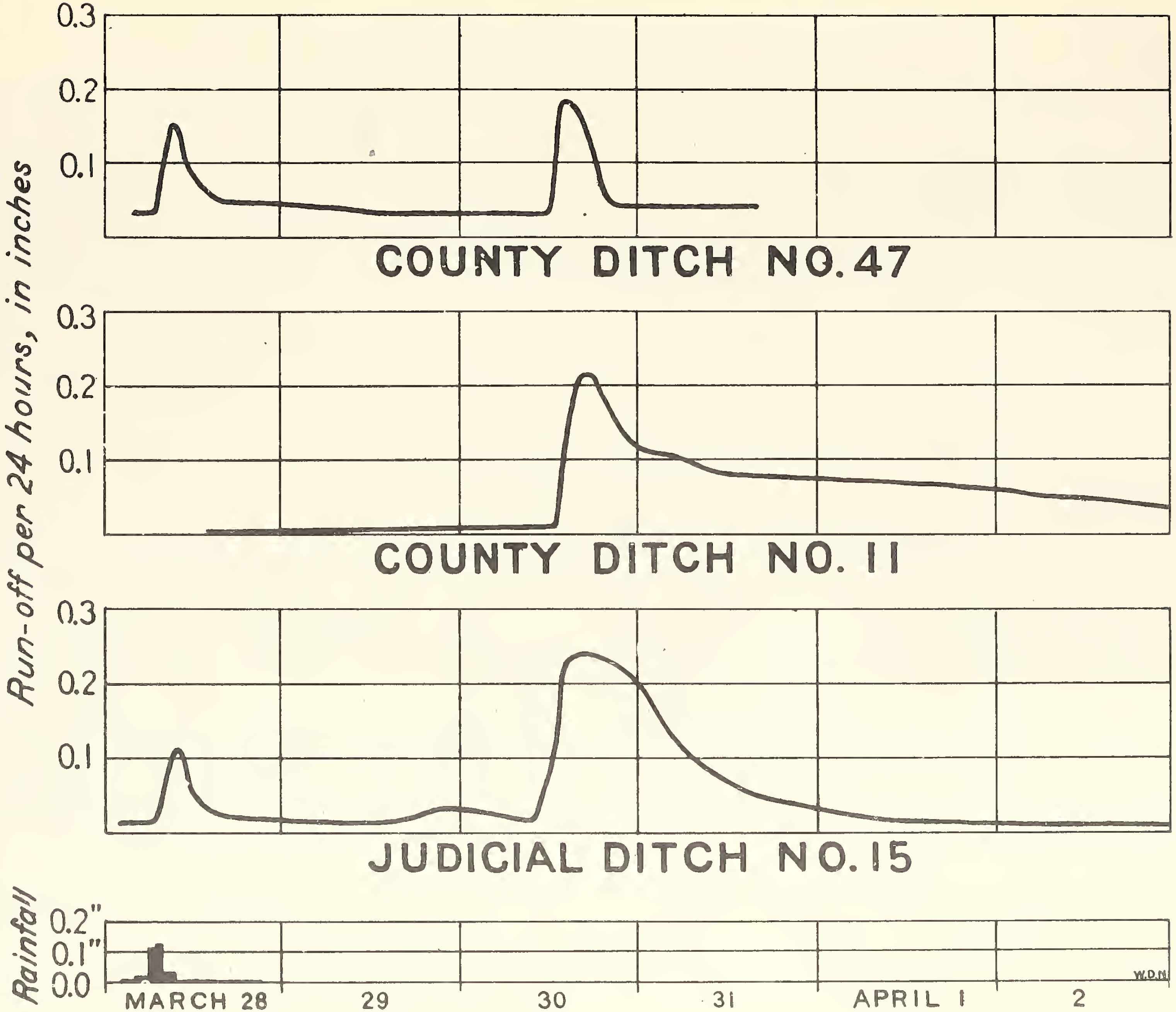

Fig. 7. Run-off Hydrographs and Rainfall Data, March-April, 1920, for Tile Drainage Systems in Murray Co., Minn. Rainfall in Inches per Hour.
Note:- The Rises on March 30 are Due to Ground Water Stored above Crust of Frost which Thawed Out and Permitted Escape of Water

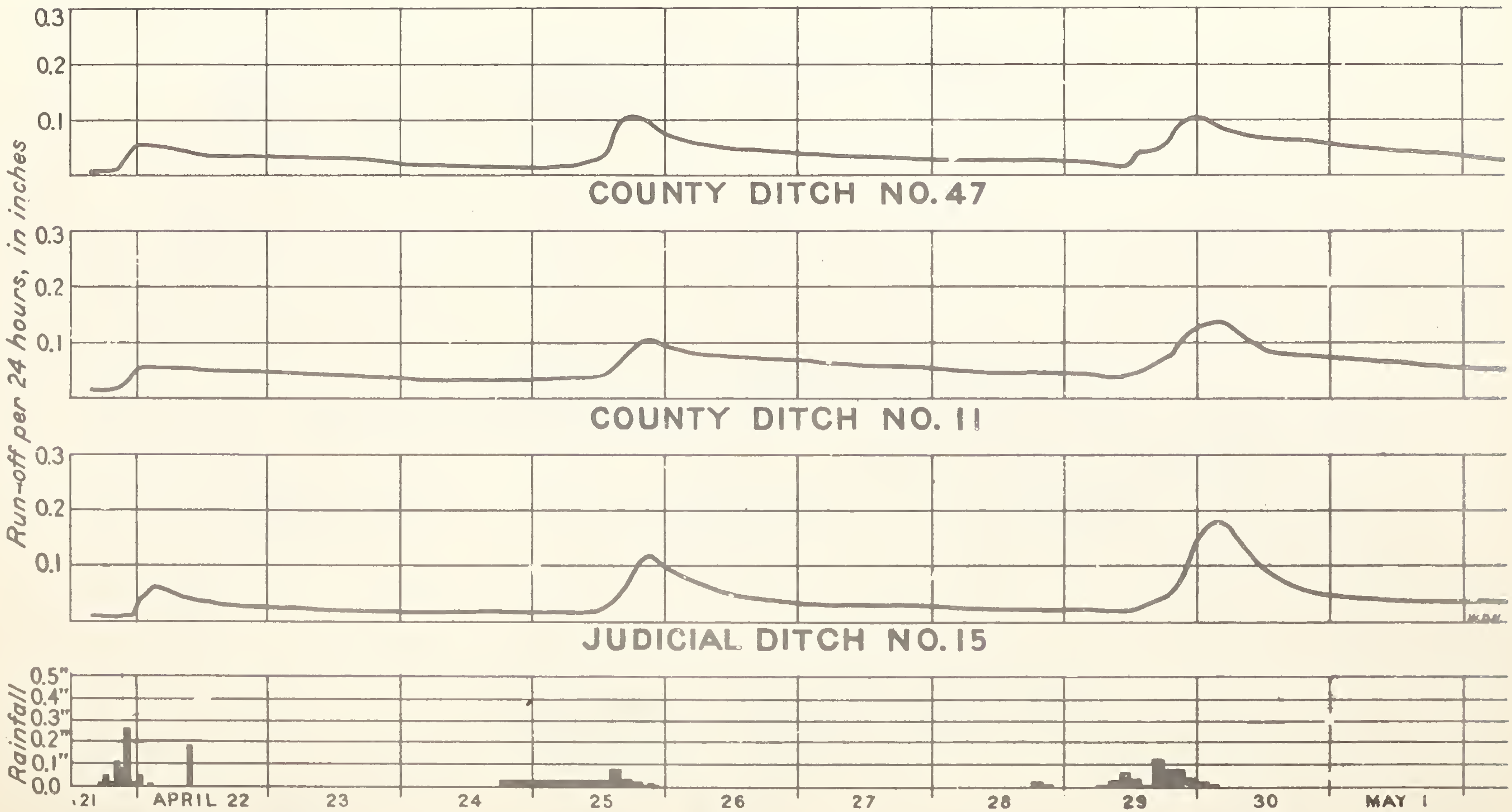

Fig. 8. Run-off Hydrographs and Rainfall Data, April – May, 1920. Rainfall shown in Inches per Hour. For Tile Drainage Systems in Murray Co., Minnesota

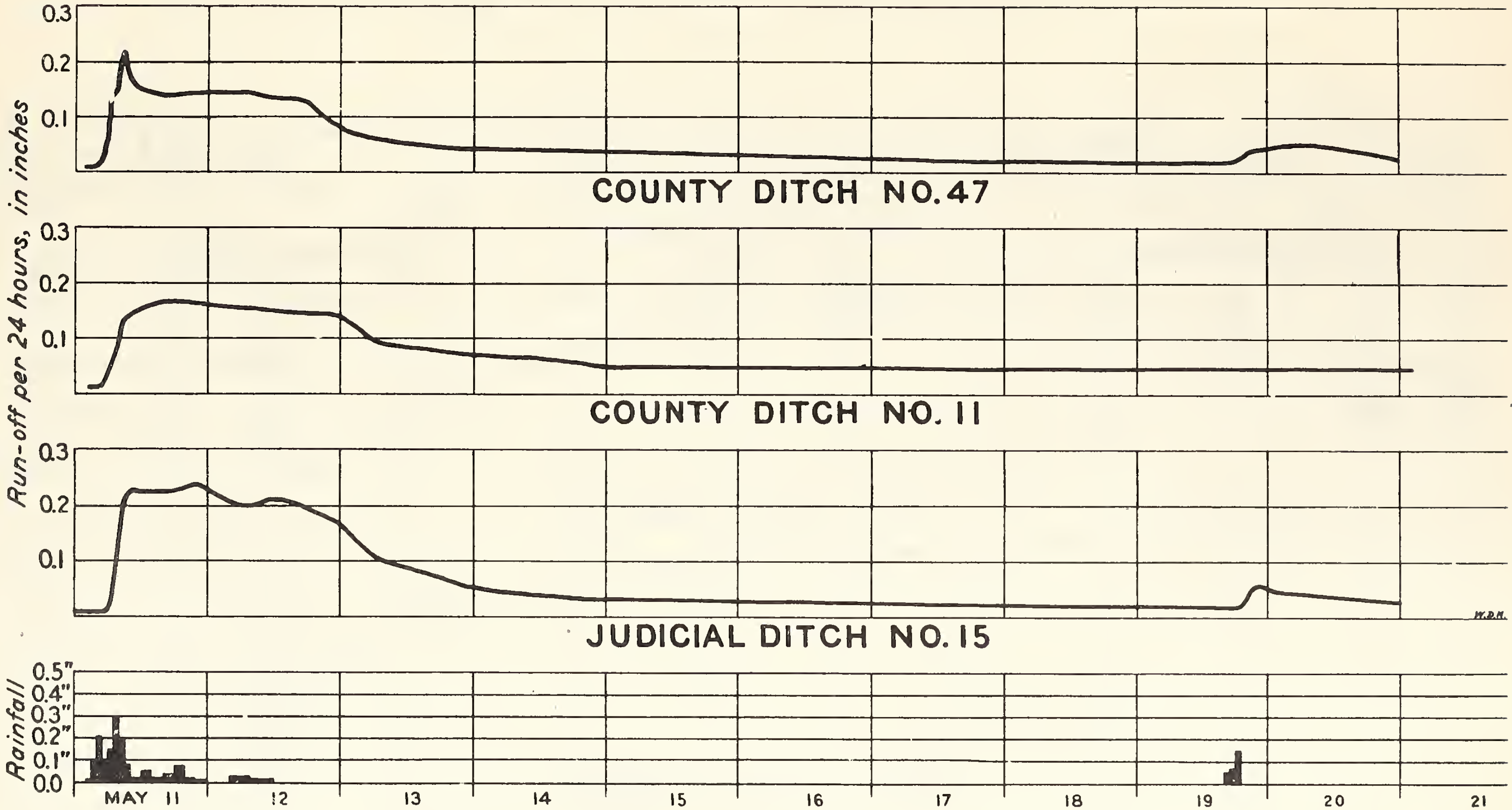

Fig. 9. Run-off Hydrographs and Rainfall Data, May, 1920. Rainfall shown in Inches per Hour. For Tile Drainage Systems in Murray Co., Minnesota

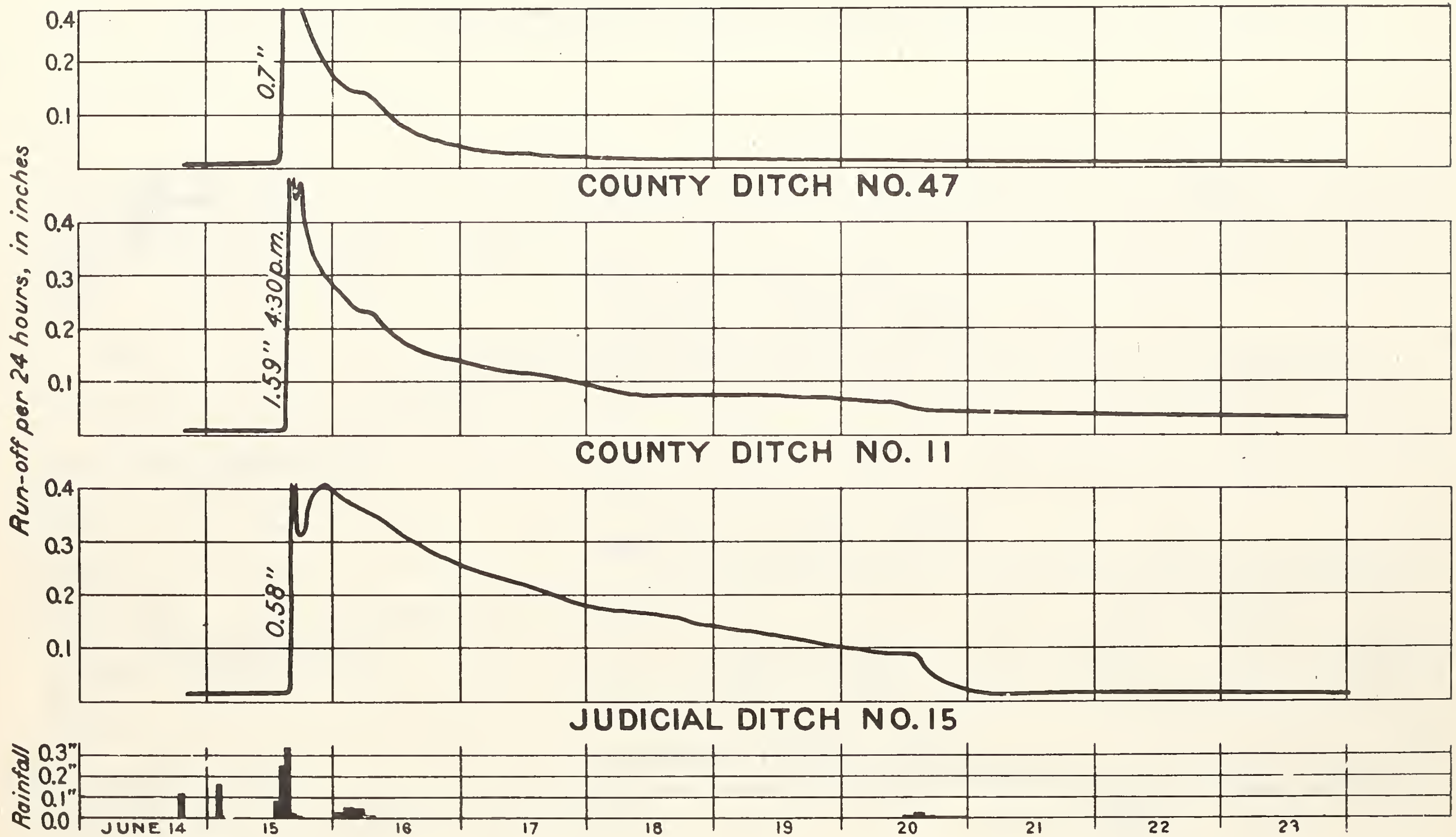

Fig. 10. Run-off Hydrographs and Rainfall Data, June, 1920. Rainfall shown in Inches per Hour.
For Tile Drainage Systems in Murray Co., Minnesota

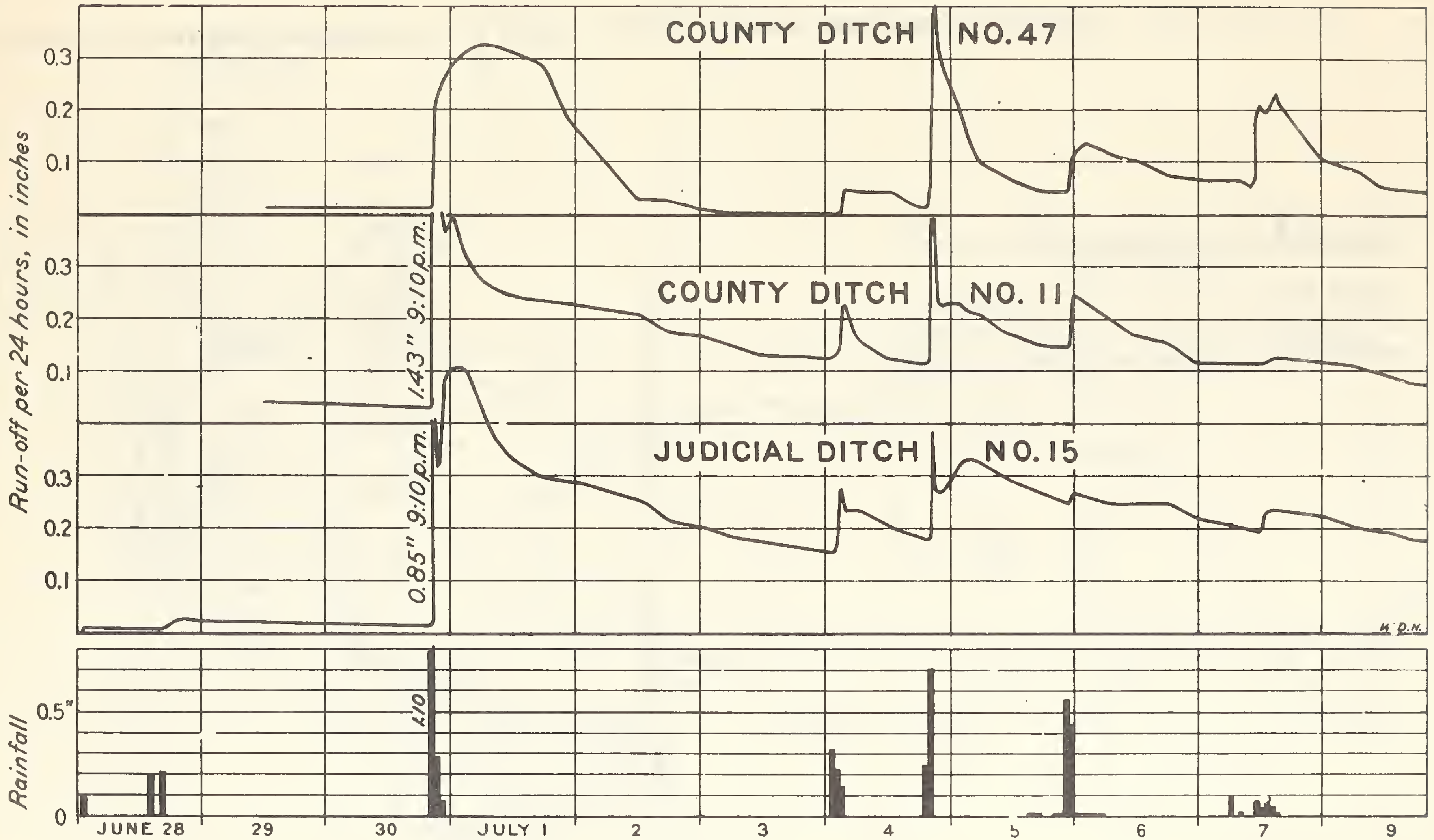

Fig. 11. Run-off Hydrographs and Rainfall Data, June-July, 1920. Rainfall shown in Inches per Hour.
For Tile Drainage Systems in Murray Co., Minnesota

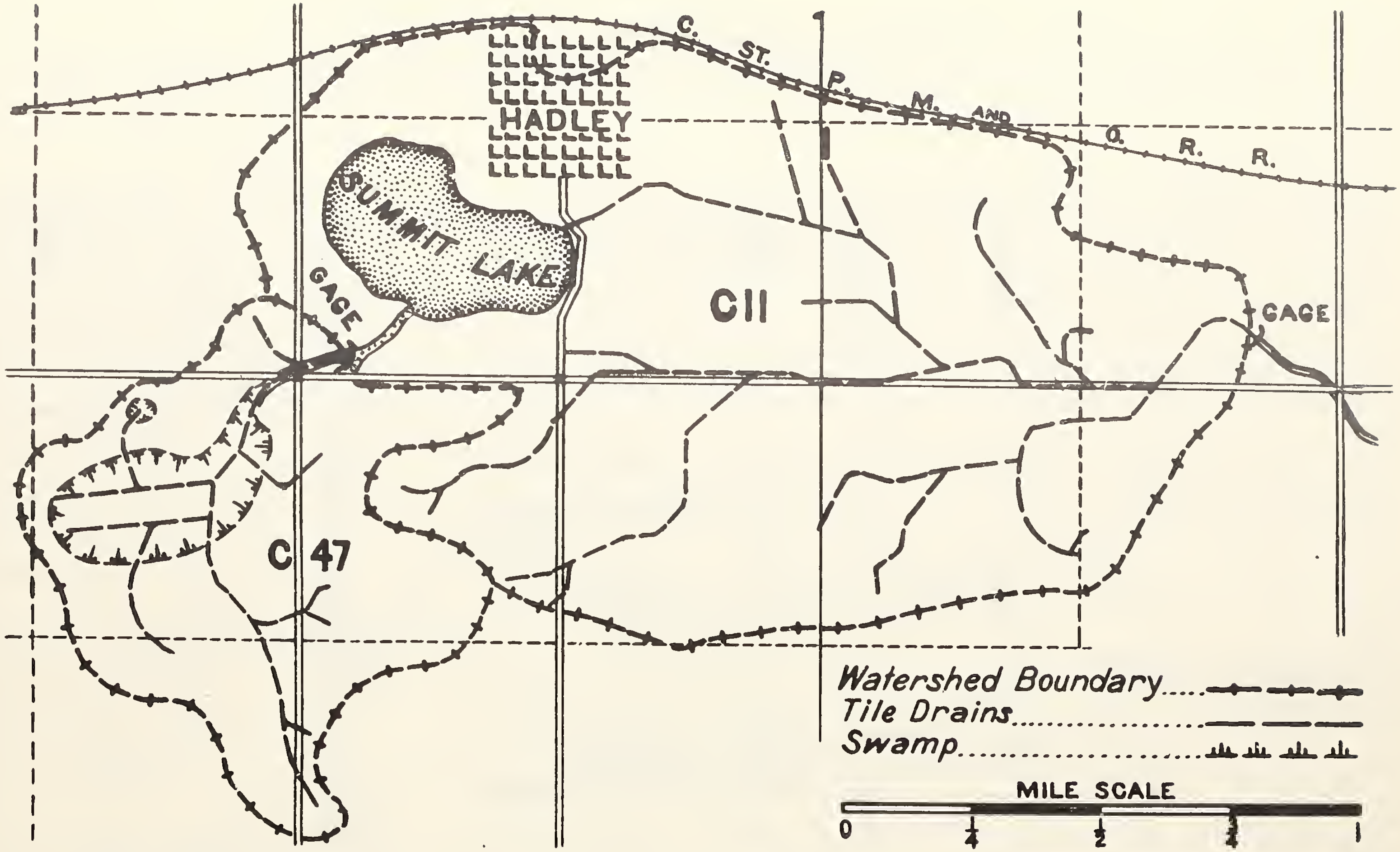

Fig. 12. Watershed Map. County Ditch No. 11 and County Ditch No. 47

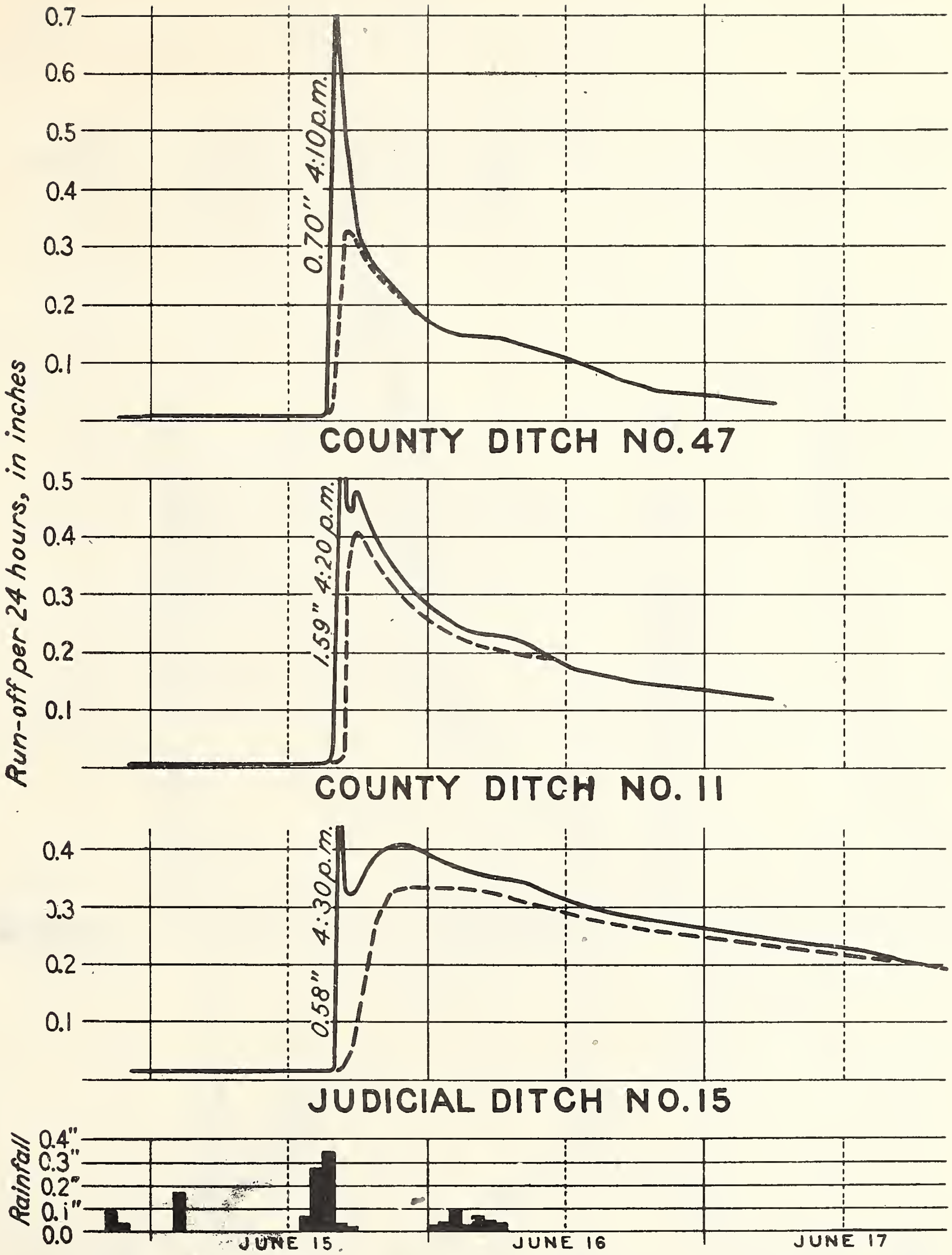

Fig. 13. Run-off Hydrographs and Rainfall Data, Maximum Rates.
Rainfall shown in Inches per Hour
Dash Line = Tile Full Line = Tile and Surface

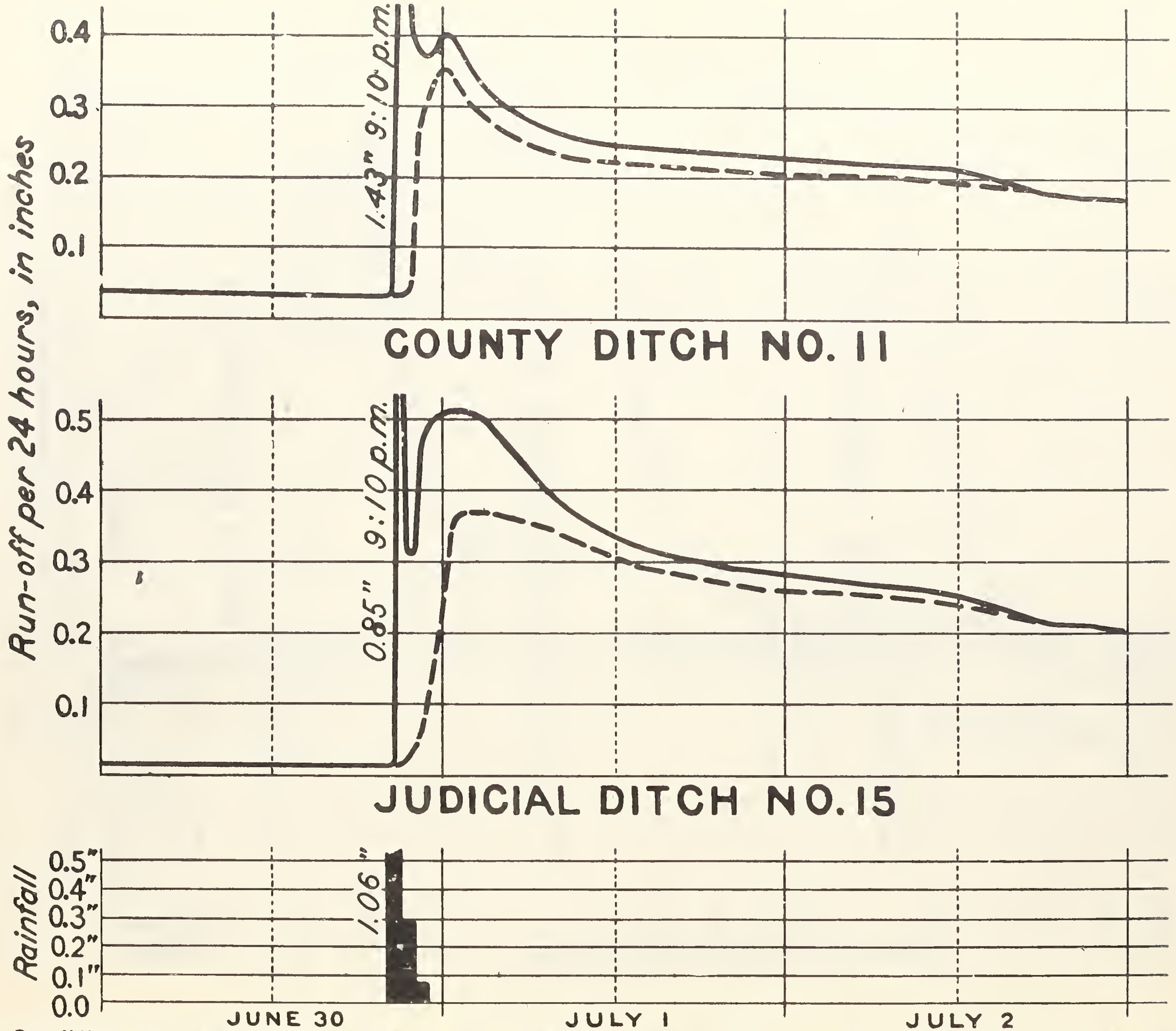

Fig. 14. Run-off Hydrographs and Rainfall Data, Maximum Rates. Rainfall in Inches per Hour. Dashed Line, Tile. Full Line, Tile and Surface

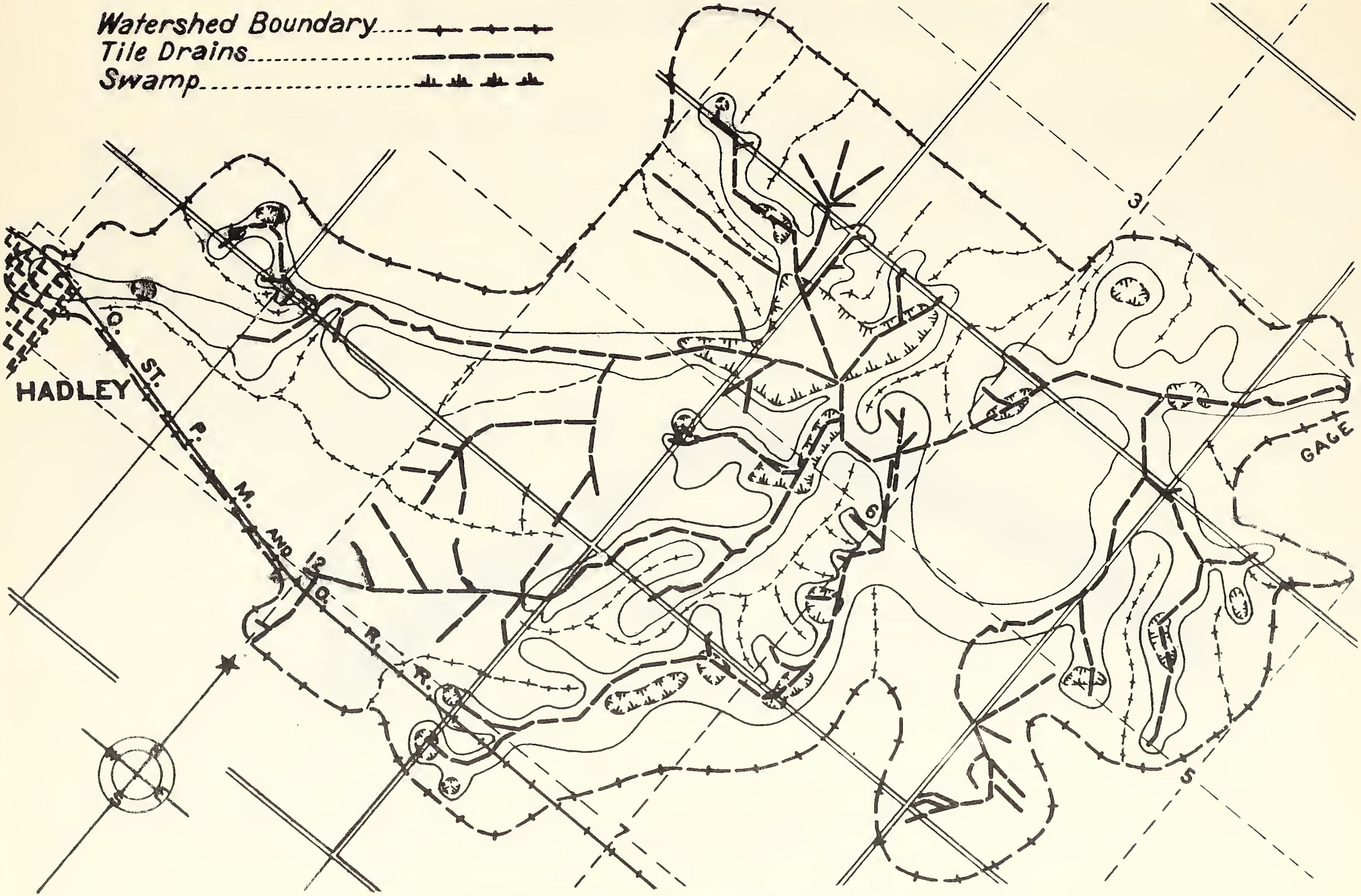

Fig. 15. Watershed Map, Judicial Ditch No. 15

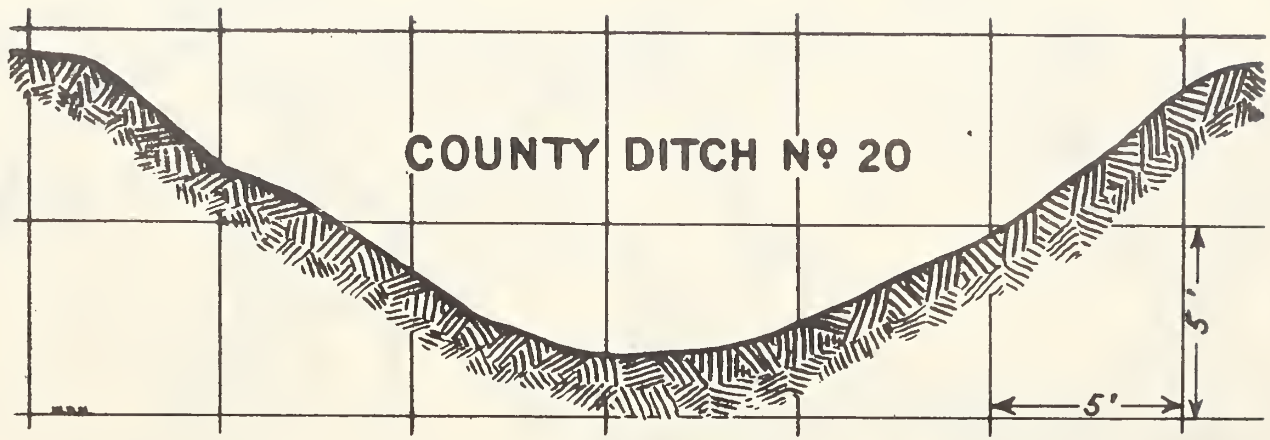

Fig. 16. Average Cross Section of County Ditch No. 20

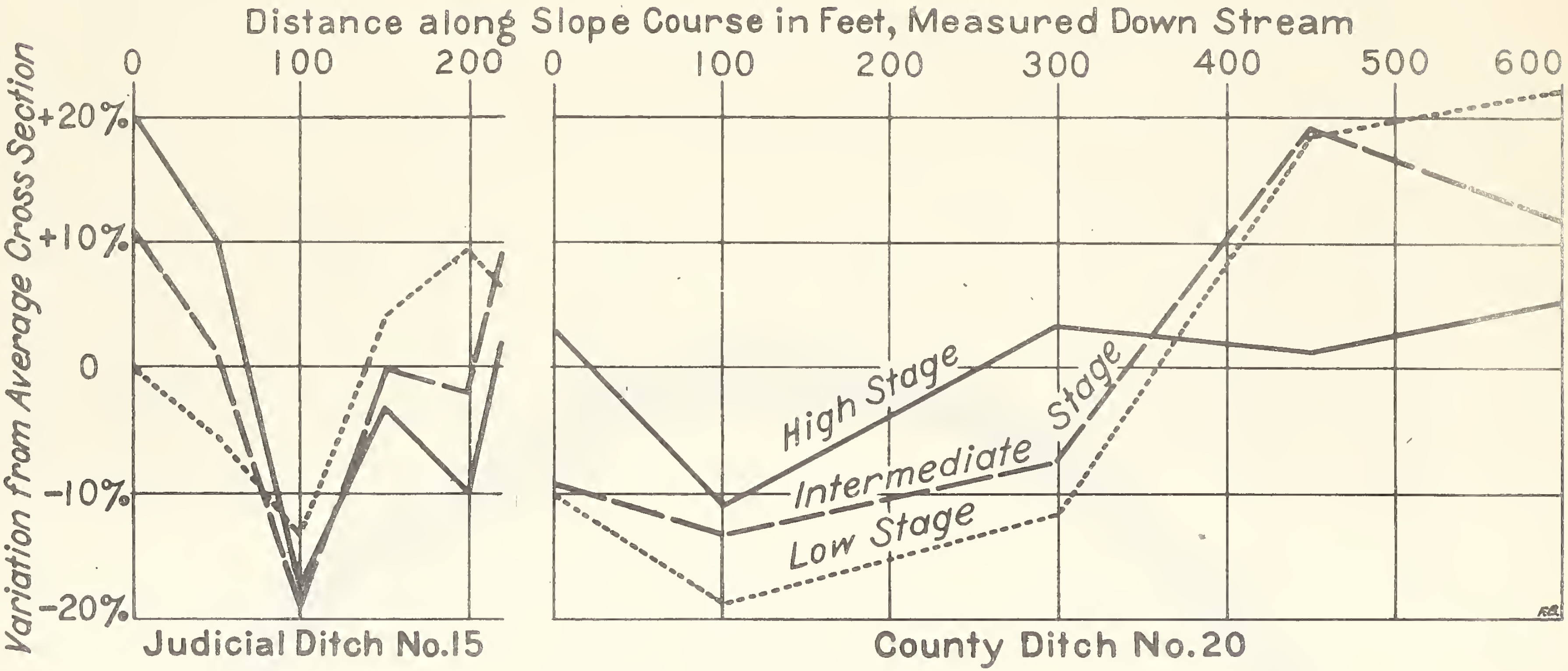

Fig.17. Graphs showing per cent Variation, from Average Cross Sectional Area for all Sections along Slope Courses

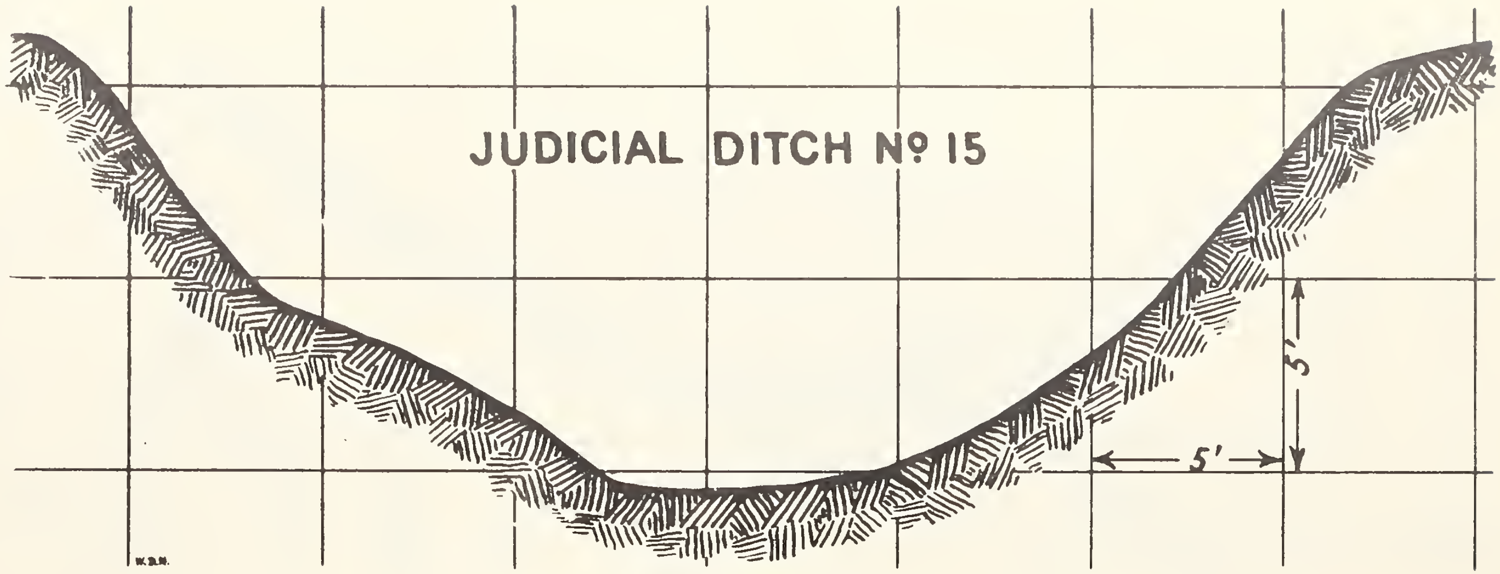

Fig. 18. Average Cross Section of Judicial Ditch No. 15

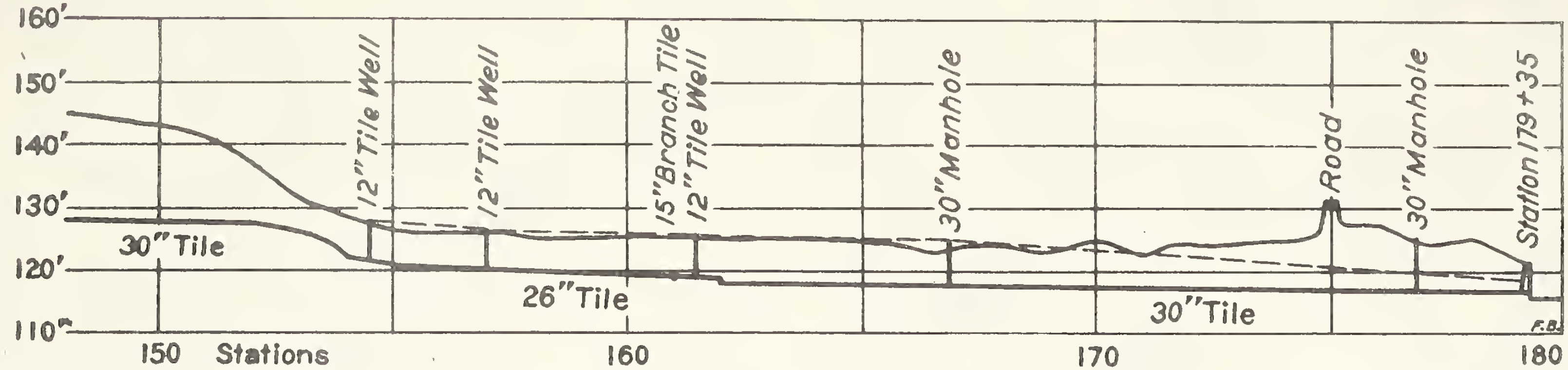

Fig. 19. Profile of Lower End of Main Tile, Judicial District No. 15